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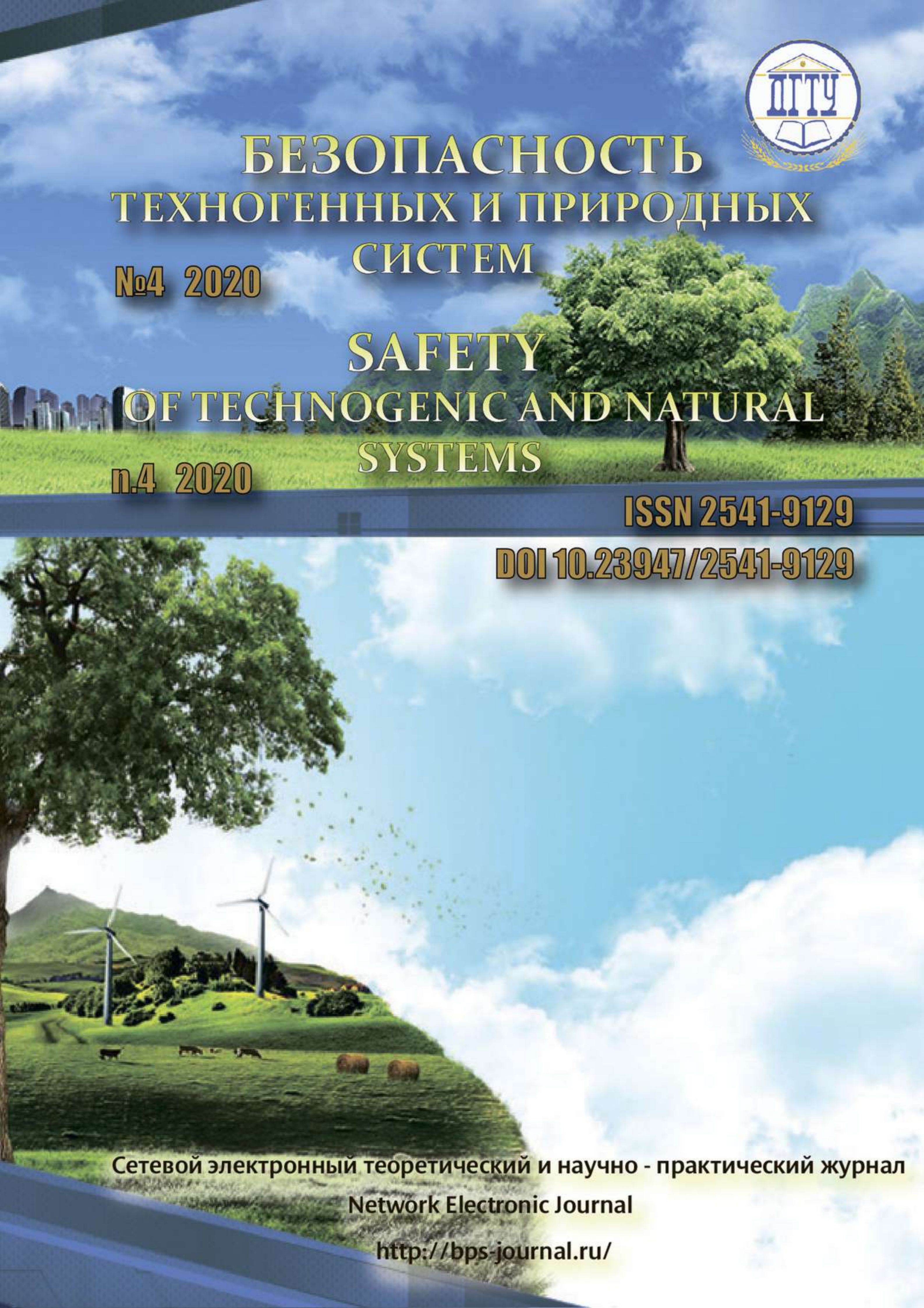

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CONTENT

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Predicting accidents in the mining industry in Zimbabwe in order to develop preventive measures to reduce them

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Introduction. Industrial accidents are associated with various factors: human, social and economic problems, which we must strive to eliminate, thereby ensuring a safe working environment. Statistics on occupational injuries are necessary to assess the degree of hazard and potential risks associated with occupational factors to protect workers. Labor inspectorate statistics play an important role in developing national policies, systems, programs and strategies to improve safety and working conditions for miners in Zimbabwe. Labor Inspection in Zimbabwe is one of the main safety control mechanisms. Labor inspection statistics enable the government to monitor the mining industry and better analyze mining safety compliance issues.

Problem Statement. The article discusses the prediction of accidents in the mining industry of the Republic of Zimbabwe in order to reduce the incidence of injuries. Economic and social development in the mining industry requires reliable analysis of injury statistics. Statistics of injuries in various production processes are given.

Theoretical Part. In the process of data analysis, interpolation algorithms are used embedded in mathematical software. Statistical reports on occupational injuries provided by the Federal State Statistics Service were used as basic information.

Conclusion. Mathematical forecasting of industrial injuries in the mining industry in Zimbabwe allows us to determine the likely values of the predicted indicators.

Keywords: Zimbabwe, analysis, forecast, injuries, mining industry, extrapolation, safety measures, probable values.

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Introduction. The contribution of the mining industry of Zimbabwe to the country's GDP is about 9 % and continues to increase. According to experts, the dynamics could be even more optimistic if it were not for the acute shortage of qualified engineers, which, as in many other African countries, hinders economic development. Zimbabwe produces more than 40 types of minerals, such as platinum, gold, nickel, copper, diamonds, and coal. The government of Zimbabwe counts on the assistance of Russia and UNESCO in reforming the mining industry by improving the competence of engineers and introducing modern technologies, improving safety and improving working conditions [1].

Artisanal and small-scale mining is one way for workers to survive the economic crisis in Zimbabwe. In the country with limited opportunities and very high unemployment, more than 90% of cooperatives help young people feed their families. Therefore, it is necessary to support miners at the state level in order to avoid deadly mining conditions.

In 2018, miners extracted 21.7 tons of minerals, while mining companies — 11.5 tons, despite the fact that miners use simple tools such as picks, shovels, ropes and buckets [2]. However, despite such a high level of production, the legislation does not regulate regulatory relations with miners working in very difficult and dangerous conditions with violations of labor protection and safety standards, which must be strictly observed in the mining industry [3]. To improve working conditions, the cooperatives of miners want to submit amendments to the law on minerals for discussion. They argue that legal regulation at the national level can improve the situation in the field of labor protection and safety, as well as contribute to the development of mining activities.

Problem Statement. The study of the causes of injuries and occupational diseases will reduce dangerous and harmful working conditions at the workplace. An accident, despite being a stochastic event, is usually affected by dangerous and harmful factors of production, as well as various deviations from its regulations. Accidents at work should be considered as signals of occupational risks, most often associated with the unsatisfactory state of preventive work to prevent injuries at the production site, in the shop, building and in general at the enterprise.

The creation of a mathematical model that can be used to predict accidents will allow the government and the mining industry of Zimbabwe to assess occupational risks and develop measures to preserve the health of workers and reduce all types of costs associated with adverse working conditions. The main goal of the study is to create a mathematical model based on the known statistical data that will allow us to evaluate the most repeated accidents and then take measures to reduce them.

Theoretical Part. For mathematical modeling of the accident forecast, we will use statistics on fatal injuries in Zimbabwe for 1990-2014. (fig. 1) [4]. The most common causes of injuries during mining are presented in (table 1) [5, 6]. Table 2 shows the operations and means that lead to injuries, as well as the corresponding causes.

Table 1

Causes and types of injuries in the mining industry in Zimbabwe

Types	Causes
Electrical injuries	Violation of the integrity and functions of tissues and organs as a result of electric current, exceeding the permissible level of electrical voltage in the network
Getting trapped in mines	Getting a miner trapped as a result of a collapse, violation of the size of passageways for people
Explosions of pressure vessels	Interruptions in the supply of compressed air, exceeding the temperature and volume of the supplied liquids and gases, violation of the integrity of the pipeline
Explosions of materials and substances	Rock fall, close proximity to the site of the explosion
Falling, rolling, or sliding of rocks in the mine	Works without safety belts, landslides, subsidence, violation of the permissible slope, lack of bypasses, bridges
Falling of the facade, edges or sides of rocks in the mine	Works without safety belts, untimely fixing of mine workings, landslides, subsidence phenomena, violation of the permissible slope, lack of bypass workings, bridges
Falling of the roof, rear, or front parts of rocks	Violation of the location and operation of hydraulic equipment, mechanisms, explosions of pressure vessels, violation of the cross-section of workings, untimely fixing of mine workings
Fires and fire injuries	Malfunction of ventilation equipment, untimely ventilation of mines, exceeding the maximum permissible concentration of explosive dust, gas, electrical connection

Table 2

Operations, means and causes of injuries

Operations and means	Causes
Processing of rock	Works with violation of the equipment operating instructions, self-modification of technological equipment without approval from the manufacturer
Hand tools	Use of the tool in the absence of an individual battery lamp, lack of personal protective equipment
Non-driving transportation	Lack of necessary barriers on the way, lack of cargo fasteners when moving, overloading wheelbarrows
Traction carriage	Lack of fencing, lack or failure of signal to start movement of the traction equipment and power supply equipment, violation of the speed of movement of the rolling stock, violation of dimensions of rolling stock
Hoists	Exceeding the truck limit, the lack of or improperly secured cargo, defective mechanism, in the area of lifting mechanisms the presence of people is forbidden, the fault of the winch, bucket, and other mechanisms

The methodological basis of the work is the analysis of accident statistics in the mining industry of Zimbabwe and the use of mathematical modeling to create an adequate model for predicting such statistics. As a result, it is

expected to be possible to predict injuries, which will allow mining companies to implement measures to prevent or eliminate accidents that may occur in the future [7].

Injury data is a complex, multi-factor statistical aberration. When analyzing random functions, it is necessary to determine the degree of error in the prediction of a random variable and which part of the sample makes the maximum error.

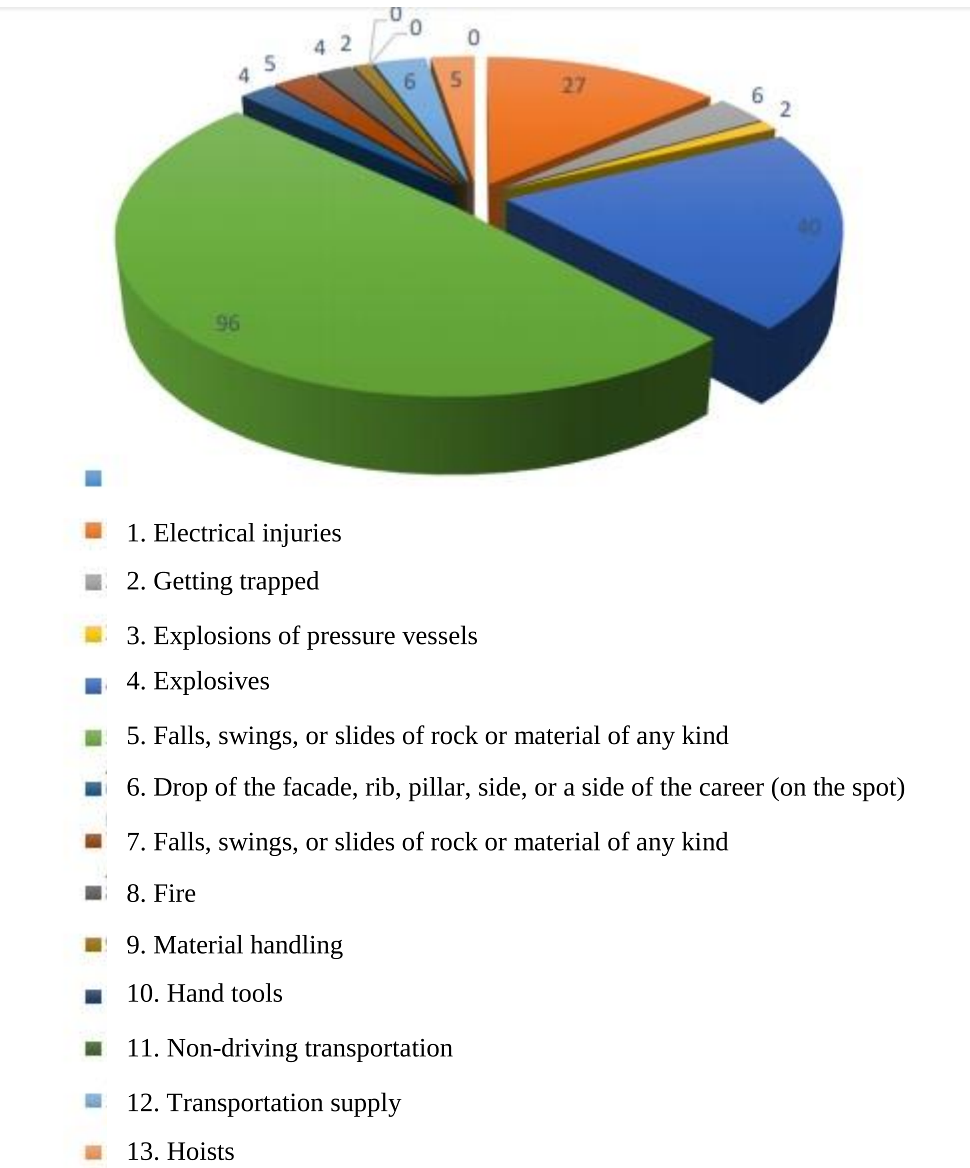

Fig. 1. Statistics on fatal mining injuries in Zimbabwe for 1990-2014

The following methods are used to analyze the statistics on occupational injuries:

— extrapolation — the main method of forecasting, which is based on forecasting events based on indicators of previous years [8];

— regression — an additional method for determining the error of calculations based on predictions in those years that are already available in statistics;

— fractal analysis is used in system diagnostics to solve problems related to the use of time series. [9];

— statistical indicators of random number sampling: arithmetic, geometric, and harmonic averages, as well as variance and coefficient R^2 [7].

In this study, we will use extrapolation (Fig. 2). Extrapolation in MathCAD is the prediction of parameter values by means of functions beyond the scope of definition. In particular, we will use the function predict *(v, m, n)*, where *v* is a vector of real values taken at regular intervals of the argument values; *m* is the number of elements of the data vector *v*, according to which extrapolation is built; *n* is the number of statistical data values that need to be predicted. This function has a built-in linear extrapolation algorithm based on the analysis of the spread of parameter values [10].

Extrapolation in MathCAD allows you to perform calculations in a mode where you can directly detect, localize, and eliminate forecast errors. The first step is to check the optimal number of parameter values for the forecast and set a specific error value. At the next stage, the vector of real values is extrapolated over the selected period, and the value of the argument is taken at regular intervals. To check the adequacy, the coefficient R^2 is used — the ratio of the variances of the original values of the data vector and the debug values calculated for the corresponding time interval.

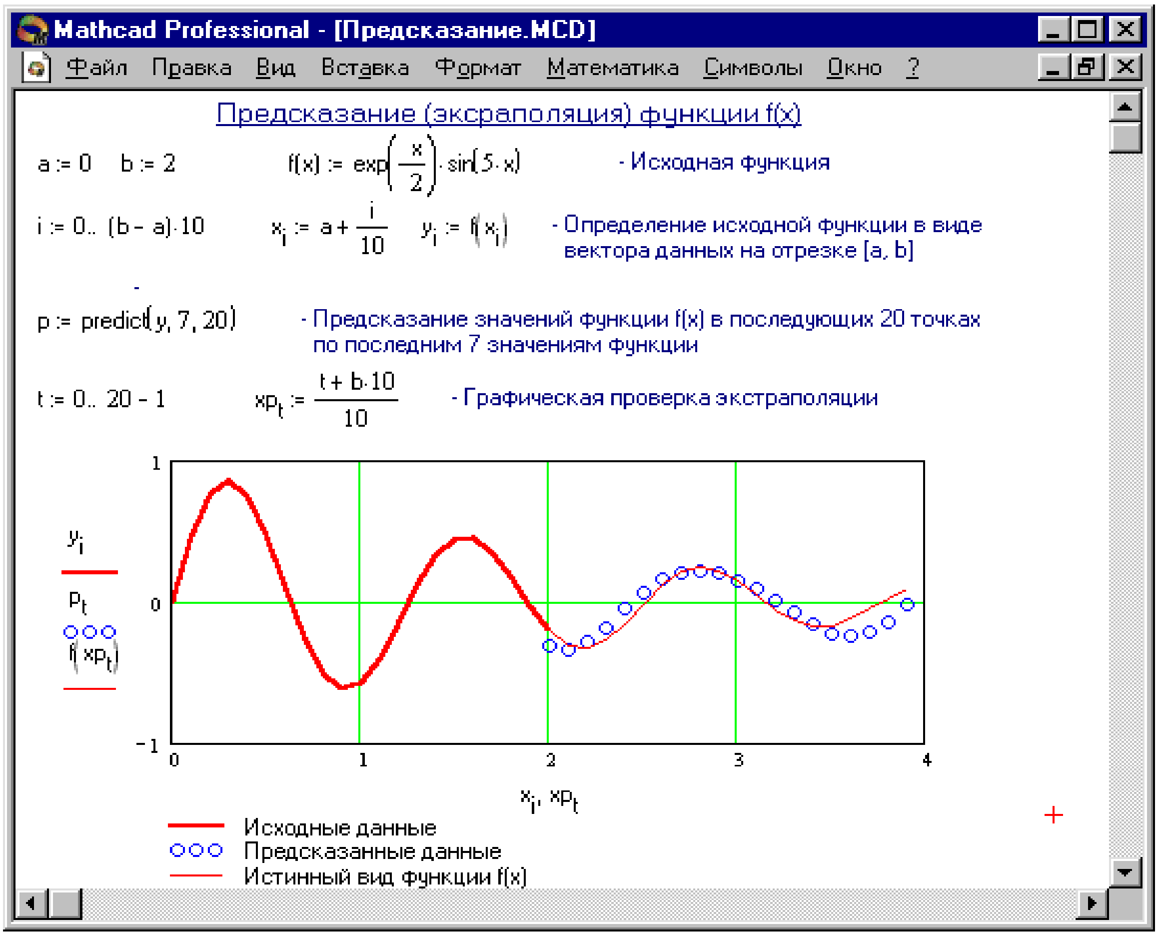

Fig. 2. Example of prediction of the values of the function f (x)

Main results of predictive calculations. Calculations and predictions were made for the types, operations, and means of injury. Figures 3-12 show the results of some calculations.

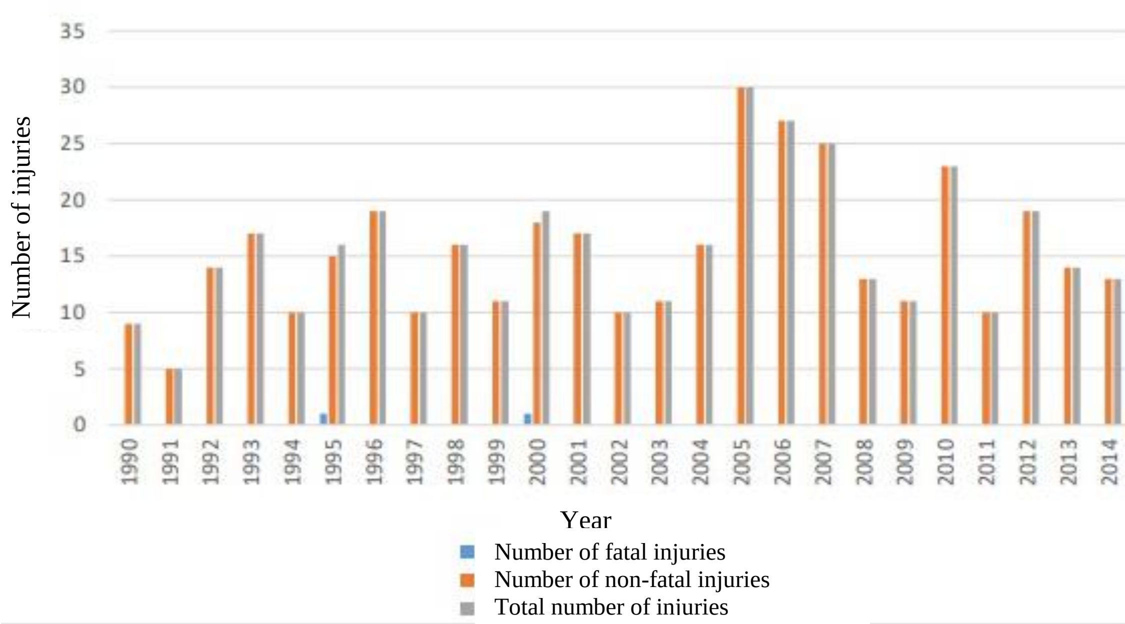

Fig. 3. Statistics of injuries in pressure vessels explosions

$$\mathrm{SR\_VYA} := \sum_{m=0}^{4} \frac{\mathrm{VYA}_m}{5} \qquad \mathrm{SR\_VP} := \sum_{m=0}^{4} \frac{\mathrm{vp}_m}{5}$$

$$\mathrm{SR\_VYA} = 15.8 \qquad \mathrm{SR\_VP} = 16.817$$

$$\mathrm{DISP\_VYA} := \sum_{m=0}^{4} \frac{(\mathrm{SR\_VYA} - \mathrm{VYA}_m)^2}{5} \qquad \mathrm{DISP\_VP} := \sum_{m=0}^{4} \frac{(\mathrm{SR\_VP} - \mathrm{VYA}_m)^2}{5}$$

$$\mathrm{DISP\_VYA} = 21.36 \qquad \mathrm{DISP\_VP} = 22.395$$

$$\mathrm{R2} := \frac{\mathrm{DISP\_VYA}}{\mathrm{DISP\_VP}}$$

$$\mathrm{R2} = 0.95377999214$$

Fig. 4. Debugging the forecast by using the coefficient R^2:.SR_VYA — the arithmetic average of the debug values from the data vector for 2010-2014; SR_VP — the arithmetic mean of the predicted values for 4 years; DISP_VYA, DISP_VP — dispersion of the two analyzed samples; R2 — regression coefficient R^2, which is equal to 5-10 %

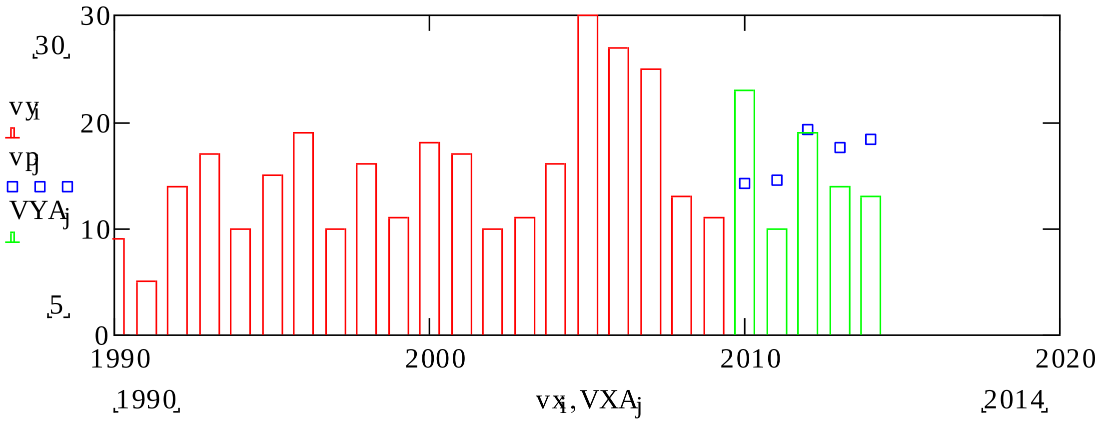

Fig. 5. Debugging the forecast using the R^2 coefficient and the predict *(v, m, n)* function for pressure vessel explosions

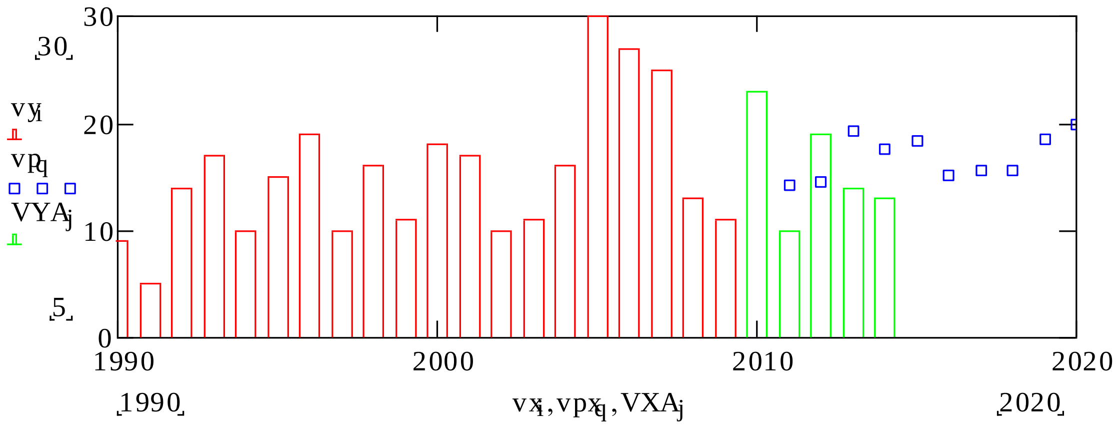

Fig. 6. Result of creating a well-established forecast until 2020 using the predict function for pressure vessel explosions

To calculate the forecast of occupational injuries, we have used statistical data on pressure vessel explosions provided by the Zimbabwe Labor Inspectorate for 2010-2014. The calculations show that the number of statistical data values that need to be predicted (parameter n) is 12 [11].

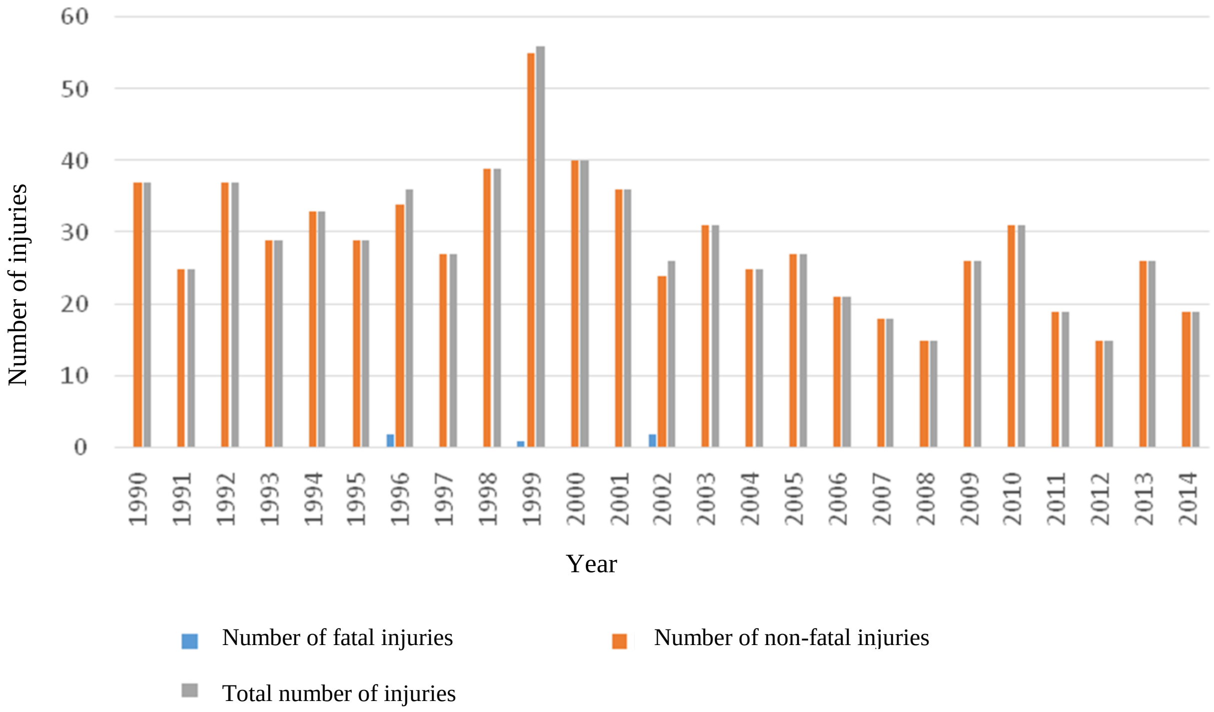

Fig. 7. Statistics of injuries caused by collapses, falls, rolling or sliding of rocks and materials of any kind

In 2016-2017, there was an increase in the number of deaths. 31.01.2018 due to the storm, the power supply to one of the mines stopped, all 955 miners were underground, and they were able to extract people from the mine only on February 2. The production and technical base of the mine was not ready for such an accident. There are many accidents in the mining industry in Zimbabwe. Such accidents are a warning to the relevant companies, which should review and improve the safety measures.

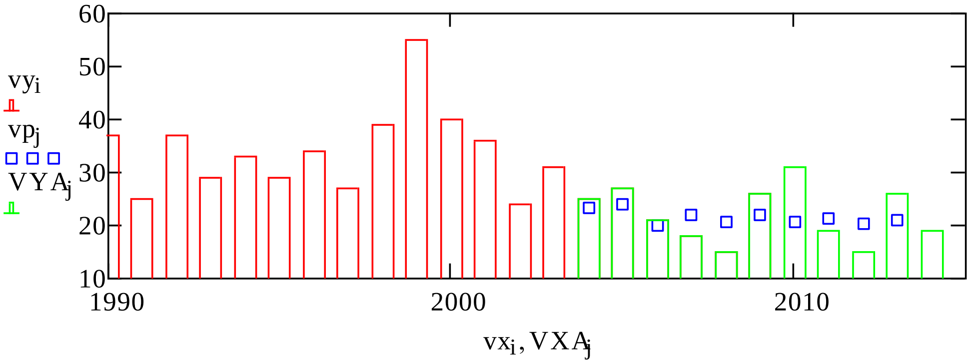

Fig. 8. Debugging the forecast using the R^2 coefficient and the predict *(v, m, n)* function for injuries caused by collapses, falls, rolling, or sliding of any type of rock or material

In February 2019, the Cricket and Silver Moon platinum mines in the small village of Battlefields, 175 km away from Harare, were flooded as a result of heavy rains. 28 miners died. Eight people were saved, but the continuing downpours made rescue efforts difficult, resulting in a large number of victims. [2].

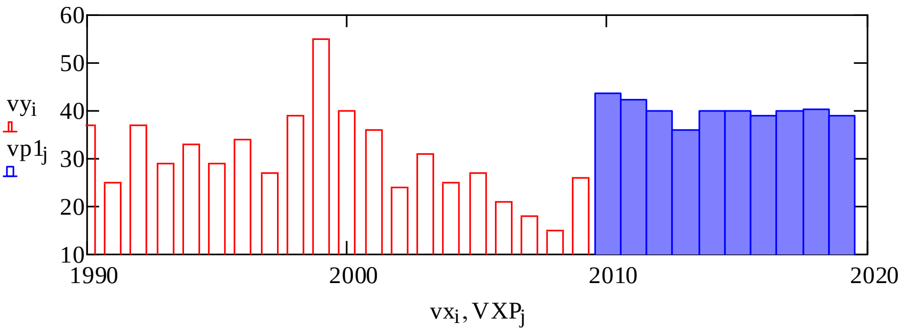

Fig. 9. Forecast for collapses, falls, rolling, or sliding of rock and material of any kind

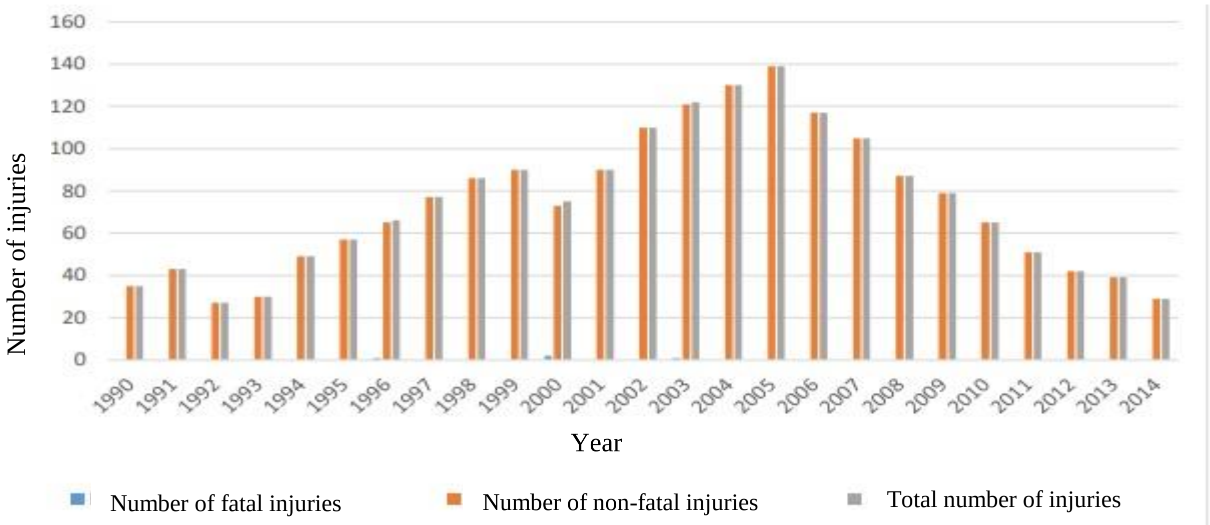

Fig. 10. Statistical data of traumatism in the fall of the facade, edges or the side of rocks in the mine

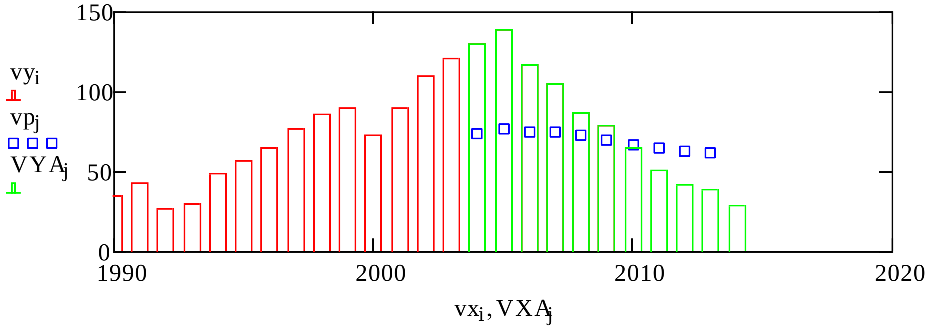

Fig. 11. Debugging the forecast by the coefficient R^2, and the predict *(v, m, n)* function in the fall of the facade, the edges or sides of rocks in the mine

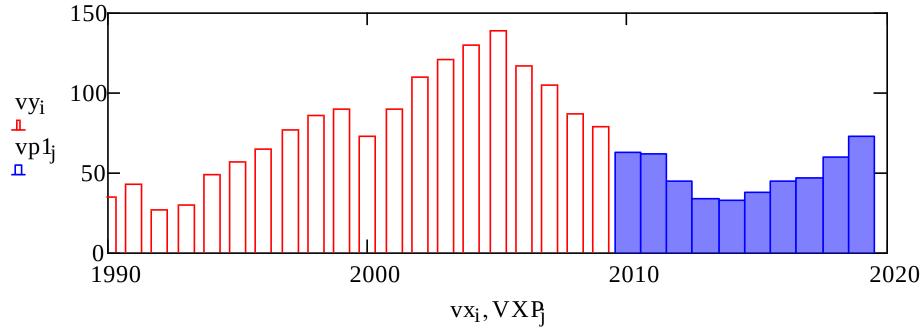

Fig. 12. Forecast of the fall of the facade, the edges or sides of rocks in the mine

Conclusion. For the sample taken as an adequacy testing example, the parameter R^2 was used, the value of which was 95.4 %. In this regard, we can conclude that the forecast error does not exceed 10 %.

Thus, mathematical forecasting of industrial injuries in the mining industry in Zimbabwe allows you to determine the possible number of accidents. This makes it possible to use such data to develop preventive measures, as well as rationally plan the allocation of funds and equipment to improve working conditions in the industry.

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I. S. Kuptsova — formulation of the main concept, goals and objectives of the research, preparation of the text; Yu. I. Bulygin — scientific supervision, analysis of research results, correction of conclusions; R. R. Lazurenko — calculations, preparation of the text; A. R. Temirkanov — formulation of conclusions, revision of the text.

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Business game as a form of effective labor protection training

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Introduction. The article analyzes the most likely damage from fatal industrial accidents. The analysis revealed the main cause of industrial accidents — violation of safety requirements during the organization of various works and their implementation in practice. A special role in the prevention of accidents is played by the process of employee training, which requires careful preparation. That is why, in order to minimize accidents and erroneous actions of personnel, it is proposed to introduce a new business game "Guardians of labor" into the practice of training.

Problem Statement. The objectives of this research: creating a business game for learning and adapting security requirements at the enterprise; developing and comparing different options for evaluating security solutions; developing information analysis skills; developing the activity of game participants.

Theoretical Part. Training in the form of a business game gives you the opportunity to work out the skills of analyzing information, evaluating and comparing different approaches to solving a problem. The authors of this study created a business game "Guardians of labor". It helps you to strengthen knowledge of occupational safety and health, fire safety, first aid and accident investigation.

Conclusion. The proposed method helps improving the professional qualities of students, develops the ability to reasonably defend their opinions and analyze alternative approaches.

Keywords: business game "Guardians of labor", training, adaptation, labor protection, safety at work, interactive training.

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Introduction. Accidents at work can cause serious damage [1]. In Russia, most fatal industrial accidents are caused by errors in the organization of work processes. One of the problems is the lack of relevant knowledge among employees.

An accident is a result of dangerous conditions and dangerous actions. The organization of training should minimize the number of dangerous erroneous actions of personnel in emergencies [2-4].

Problem Statement. The purpose of this research is to develop a training methodology in the form of a business game that concisely presents and visualizes the security requirements at the enterprise, and will allow you to develop skills in analyzing information that is important for professional activity. In this case, the group of players deepens their knowledge by working out different game situations [5]. As part of this training process, you can, in particular, master the content and application of special documents in production practice: instructions, regulations, etc.

The goal of the game is to get knowledge on labor protection. To achieve this goal, you need to solve a number of tasks:

— to develop the ability to analyze information;

— to develop the ability to assess the practical potential of various proposals;

— to develop students' initiative.

Theoretical Part. Training in the form of a business game allows you to learn information through the interaction of participants. This is the most effective method of perception of information. Due to the physiological features of memory, a person perceives the largest amount of information (up to 90 %) through practice and action. The results in reading and listening are usually much lower (up to 20-30% is absorbed) [6].

Based on these data and the motives of the business games on labor protection "Gold of Alaska" and "Martian Chronicles", the authors have created their own analog — "Guardians of Labor". The new product will increase the effectiveness of studying current standards and requirements in the field of industrial safety, help realize responsibility for organizing safe working conditions, learn to reasonably defend your opinion, and improve teamwork skills. It should be noted, that participation in the game requires knowledge of the relevant theory and some training [7-10].

The proposed game systematizes questions on occupational health, fire safety, first aid, accident investigation, protective equipment and safety signs. Players draw cards with questions (Fig. 1).

Fig. 1. Game cards of the game "Guardians of Labor"

Then the participants move around the entire playing field (Fig. 2) and extinguish ignorance.

Fig. 2. "Guardians of Labor": playing field

At the same time, the team needs to work together. Managers, employees, outsourcers, specialists in the field of labor protection, representatives of training centers, etc. can participate in the game.

Participants start from the "Forward" cell and draw one card from category 4. If the question is answered correctly, the player receives a PPE set (a chance to save himself from one accident). In case of an incorrect answer, the employee misses this chance, the card is returned to the bottom of the deck.

Some cells are marked with special icons. The player performs additional tasks if his chip is in one of the cells listed below.

— "Accident". You had an accident. If you have the "Protection" card, you get a chance to continue the game and roll the dice again. Without this card, you leave the playing field on the 2nd round of the game.

— "SR expertise", "SAWC", "SR Audit". The organization has conducted an examination of safety regulations (SR), a special assessment of working conditions (SAWC), and an audit of SR. Take an additional card from category 1 (occupational health and safety cards).

— "Fire". There was a fire at the facility. To increase the level of security, take an additional card from category 5 (security signs).

— "Get a bonus". When you pass the corner cell, you will receive an additional token.

— "Workwear" cell. You were given a new set of special clothing. Take a card from category 4 (PPE).

— "Imprisonment". For gross violation of labor protection requirements, you miss a move.

— "Medical". You need to pass a medical examination. Make an extra move.

— "Certification". You must pass the certification. Take one card from each category.

Participants can consult with each other and offer game solutions. For each correct answer, the team receives a point (token), and for an incorrect answer — zero points. The winner is the group that gets the most number of points [11, 12].

Conclusion. Thus, the proposed business game increases the effectiveness of studying labor protection requirements at enterprises. The solution allows you to develop the skills necessary for industrial safety specialists. The focus of players' attention moves from theory (terms, current regulations and requirements in the field of industrial safety) to the practice of formulating and protecting their own decisions, as well as analyzing the opinions of other team members.

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Calculation of collective risk of foundry professional groups based on the analysis of individual risk of each employee

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Introduction. The article presents the technique of the definition of integral risk in the organization, on the basis of which the collective risk of several professional groups involved at the foundry is calculated.
Problem Statement. The purpose of this study is to calculate the collective risk in the foundry.
Theoretical Part. The initial data are the values of individual occupational risk of employees depending on their age, work experience, gender and disability, as well as the quality of working conditions, injury risk and susceptibility to the development of occupational diseases.
Conclusion. The results of the calculation indicate a high collective risk of professional groups of the foundry, which requires the development of corrective engineering or organizational measures.

Keywords*:* foundry, working conditions, professional groups, individual and collective risk.

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Introduction. The tasks to reduce harmful and (or) dangerous effects of industrial environment factors that cause injuries and the development of occupational diseases of employees are considered as one of the highest priorities in our country. In this regard, the vast majority of enterprises must ensure the effective functioning of the Occupational Health and Safety Assessment System (OHSAS), aimed at predictive assessments of working conditions and safety. To do this, there are currently a huge number of different methods for predicting risks, which the employer has the right to choose independently.

Relevance of the Research Topic. Unfortunately, the experience of studying this issue shows that mostly the least advanced methods are used, which are not able to take into account absolutely all the factors that affect the risk. For example, at one of the machine-building enterprises of the Rostov region (OOO "PK "NEVZ", Novocherkassk) the matrix method of risk assessment is used by which the occupational health service of OOO "PK "NEVZ" managed to build a risk map (Fig. 1), which shows the units of the enterprise that are most exposed to risk-contributing factors.

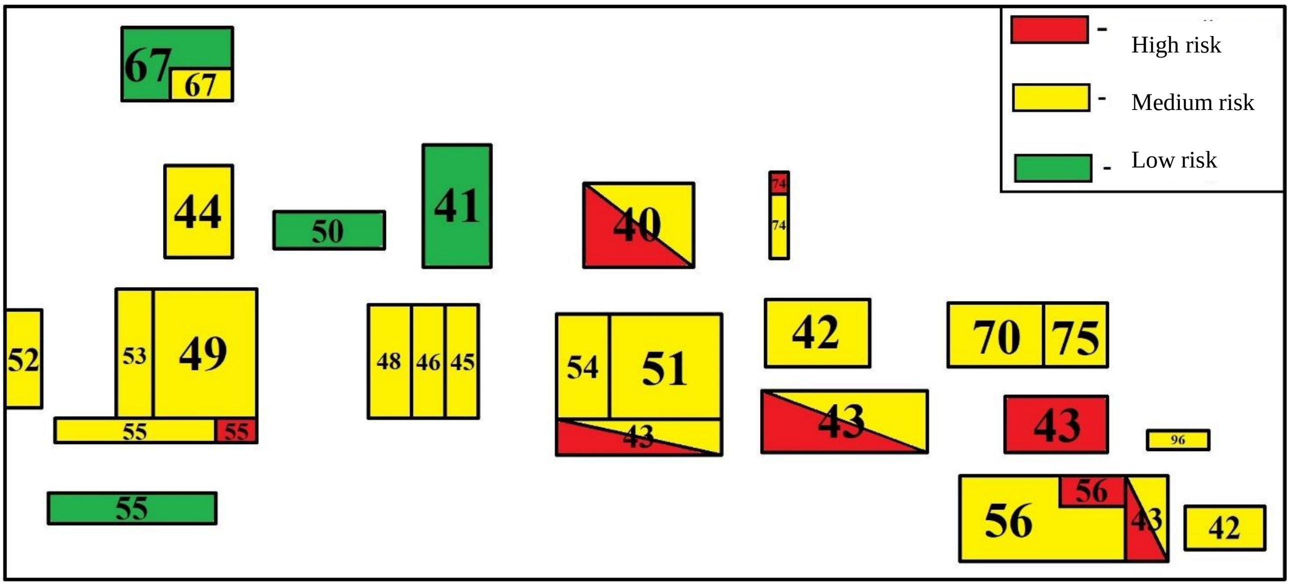

Fig. 1. Risk map of the OOO "PK "NEVZ"

However, there was revealed a number of shortcomings during the analysis of the application of this method in the foundry No. 40:

— only hazards are considered as input data for the assessment, while the amount of harmful factors, significantly contributing to occupational risk, remain unaccounted for;

— there is no risk assessment for occupational diseases;

— the role of the degree of protection of employees with personal protective equipment that reduces the negative impact of environmental factors is not clear;

— health status of employees is not taken into account, the deterioration of which may aggravate the impact of harmful and (or) dangerous factors;

— employees' personal data (gender, age, work experience), which may indicate the reasons for violations of labor protection requirements and may help identify them in the future, are not taken into account.

The method of assessment of collective exposure of workers compensate for all of the above disadvantages, which is a statistical value obtained by analyzing records of individual occupational risk (IOR) of employees, classified by professions or by business units.

Problem Statement. In addition to the methodology for IOR determination, which is the basis for collective risk calculation, there are other numerical methods for assessing risk for an employee, but their application directly affects the reliability of the result. For example, in [1], the previously mentioned matrix method is presented, which consists in expert determination of the probability levels of an adverse event and the severity of its consequences. The result of risk assessment using the matrix method is the construction of a matrix in which the classification of risks is made depending on their magnitude (table 1). There are acceptable risks (< 20), medium risks (from 20 to 39), strong risks (from 40 to 99) and unacceptable risks (> 100).

Table 1

Risk matrix

Severity (coefficient) / Probability of impact (coefficient)	Non-life-threatening injuries (2)	LIGHT (6)	MEDIUM (10)	HIGH (20)
Seldom (2)	4	12	20	40
Often (6)	12	36	60	120
Very often (10)	20	60	100	200

The advantages of this method are its simplicity and low requirements for expert qualification.

The logical-probability method [2] is much more accurate than the matrix method. Its advantage is associated with the assessment of the possibility measure of adverse events implementation, including actual values of the impact parameter s and susceptibility parameter value r defined on the basis of hygienic standards. As a result, based on the data obtained, we can construct a possible form of the function for the implementation of any adverse event (Fig. 2).

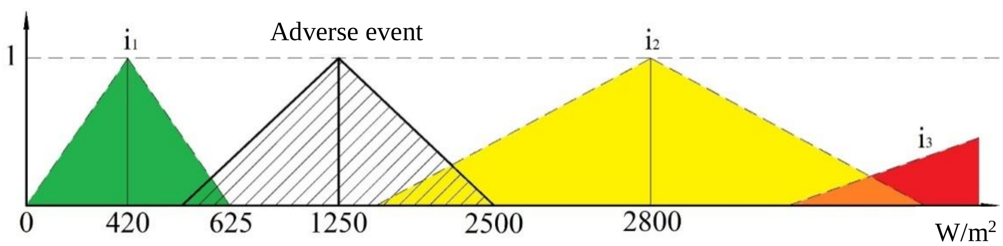

Fig. 2. The possible form of the function of implementation of an adverse event when exposed to thermal radiation: i_1 — easy outcome; i_2 — difficult outcome; i_3 – fatal outcome

The purpose of this study was to determine the collective risk of employees of the most numerous and exposed to workplace hazards professional groups of the foundry, based on the values of their individual risk of injury and the development of occupational diseases.

The objects of the study, i.e. professional groups, were represented by employees of the professions "Molder", "Hand-formed rod maker" and "Metal and alloy smelter". The number of employees is shown in table 2.

Table 2

Number of employees of some professional groups of the foundry of the OOO "PK "NEVZ"

	Number of employees in the profession		
	"Molder"	"Hand-formed rod maker"	"Metal and alloy smelter"
at all similar workplaces	10	24	4
among them:			
women	9	17	0
persons under the age of 18	0	0	0
disabled persons allowed to perform work at this workplace	0	4	0

The initial data for the calculation of collective risk were the values of employees' IOR depending on their age, work experience, gender and disability (table 3) [3-5].

Table 3

IOR values of employees of some professional groups of the foundry of the OOO "PK "NEVZ"

Gender	Age	Experience	Disability	IOR values of employees in the profession		
				"Molder"	"Hand–formed rod maker"	"Metal and alloy smelter"
men	18–27	0–10	–	–	0.23	–
	28–37	11–20	–	–	0.30	0.34
	38–47	21–30	+	0.48	0.43 (0.86)*	0.46
	48–57	31–40	+	–	0.45 (0.59)	–
	58–67	41–50	–	–	–	–
women	18–27	0–10	–	0.25	0.20	–
	28–37	11–20	–	0.37	0.35	–
	38–47	21–30	–	0.44	0.36	–
	48–57	31–40	+	0.51	0.41 (0.62)	–
	58–67	41–50	+	–	0.56 (0.83)	–
* the values of IOR for employees with disabilities are shown in parentheses						

Theoretical Part. For the calculation basis for collective risk finding, the method of determining the integral indicator of the level of occupational risk in organizations [6] is taken, which includes the following sequence:

1. Summation of the values of IOR of each employee's individual professional group (IOR_i):

$$КР = \sum_{i=1}^{m} IOR_i, \tag{1}$$

where m — the number of employees in the professional group.

$$КР_з = 0{,}48 + 0{,}25 \cdot 3 + 0{,}37 \cdot 3 + 0{,}44 \cdot 2 + 0{,}51 = 3{,}73;$$

$$КР_с = 0{,}23 \cdot 2 + 0{,}30 + 0{,}43 + 0{,}86 + 0{,}45 + 0{,}59 + 0{,}20 \cdot 7 + 0{,}35 \cdot 5 + 0{,}36 + 0{,}41 + 0{,}62 + 0{,}56 + 0{,}83 = 9{,}02;$$

$$КР_п = 0{,}34 \cdot 2 + 0{,}46 \cdot 2 = 1{,}60.$$

2. Calculation of the average value of the collective risk of a separate professional group:

$$КС = КР/m. \tag{2}$$

$$КС_з = 3{,}73/10 = 0{,}37;$$

$$КС_с = 9{,}02/24 = 0{,}38;$$

$$КС_п = 1{,}60/4 = 0{,}40.$$

3. Summation of squared deviations of IOR values of every employee of each individual professional group from the mean collective risk value of individual professional group:

$$КК = \sum_{i=1}^{m}(IOR_i - КС)^2. \quad (3)$$

$$КК_з = (0,48-0,37)^2 + (0,25-0,37)^2 \cdot 3 + (0,37-0,37)^2 \cdot 3 + (0,44-0,37)^2 \cdot 2 + (0,51-0,37)^2 = 0,0847;$$

$$КК_с = (0,23-0,38)^2 \cdot 2 + (0,30-0,38)^2 + (0,43-0,38)^2 + (0,86-0,38)^2 + (0,45-0,38)^2 + (0,59-0,38)^2 + (0,20-0,38)^2 \cdot 7 + (0,35-0,38)^2 \cdot 5 + (0,36-0,38)^2 + (0,41-0,38)^2 + (0,62-0,38)^2 + (0,56-0,38)^2 + (0,83-0,38)^2 = 0,8584;$$

$$КК_з = (0,34-0,40)^2 \cdot 2 + (0,46-0,40)^2 \cdot 2 = 0,0104.$$

4. Determination of the collective risk value of a particular professional group:

$$КВ = (m-1)/КК. \quad (4)$$

$$КВ_з = (10-1)/0,0847 = 106,26;$$

$$КВ_с = (24-1)/0,8584 = 26,79;$$

$$КВ_п = (4-1)/0,0104 = 288,46.$$

5. Calculation of the weighted average value of the collective risk of a separate professional group:

$$К = КВ \cdot КС. \quad (5)$$

$$К_з = 106,26 \cdot 0,37 = 39,32;$$

$$К_с = 26,79 \cdot 0,38 = 10,18;$$

$$К_п = 288,46 \cdot 0,40 = 115,38.$$

6. Summation of weighted average values of collective risks of the analyzed professional groups:

$$СК = \sum_{j=1}^{n}(К_j), \quad (6)$$

where j — the number of analyzed professional groups.

$$СК = 39,32 + 10,18 + 115,38 = 164,88.$$

7. Summation of the weights of collective risk values of the analyzed professional groups:

$$СКВ = \sum_{j=1}^{n}(КВ_j). \quad (7)$$

$$СКВ = 106,26 + 26,79 + 288,46 = 421,51.$$

8. Determination of total collective risk of the analyzed professional groups:

$$КР_\Sigma = СК/СКВ. \quad (8)$$

$$КР_\Sigma = 164,88/421,51 = 0,39.$$

Table 4 summarizes the values of indicators of collective risk of the studied professional groups calculated according to the described method.

Table 4

Results of collective risk calculation of professional groups of the foundry of the OOO "PK "NEVZ"

No.	Indicator	The values of the collective risk indicators of professional group		
		"Molder"	"Hand-formed rod maker"	"Metal and alloy smelter"
1	КР	3.73	9.02	1.60
2	КС	0.37	0.38	0.40
3	КК	0.0847	0.8584	0.0104
4	КВ	106.26	26.79	288.46
5	К	39.32	10.18	115.38
6	СК	164.88		
7	СКВ	421.51		
8	$КР_\Sigma$	0.39		

The value $КР_\Sigma = 0.39$ indicates a high collective risk of professional groups. Moreover, the main contribution to the collective risk is made by "Hand-formed rod maker" (Fig. 3). This fact is the reason for the development of risk control actions, which are implemented in the following priority:

— elimination of the danger, if possible;

— replacement of equipment, modification of the technological process if possible, use of safer materials and substances;

— engineering and technical solutions, construction of fences, application of security equipment, alarm devices, etc. ;

— application of warning marks, inscriptions, security signs, administrative control methods, documented operational procedures, instructions, training, control over the execution of the procedures;

— use of personal protective equipment (PPE), ensuring control over their proper use and care.

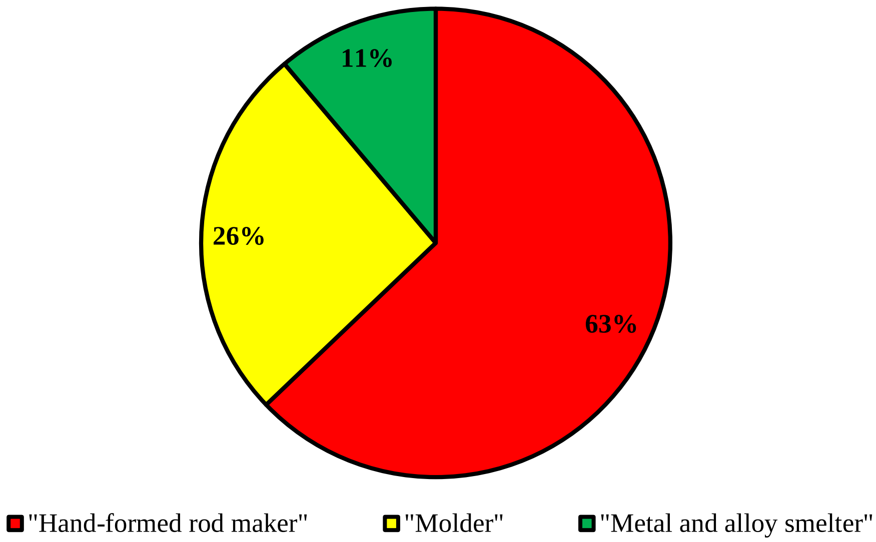

Fig. 3. Contribution of the analyzed professional groups to the total collective risk

As a possible option to reduce the professional risk of a "Hand-formed rod maker" and, accordingly, the collective risk in the foundry of OOO "PK "NEVZ", we can offer automation of the technological process of manufacturing casting rods, which involves the commissioning of molding machines, and, in addition, the introduction of cold-hardening mixtures. The advantages of cold-hardening mixtures are:

— absence of toxic emissions;

— reduction of dust emission when knocking out forms;

— hardening without exposure to high temperatures [7].

Thus, this approach will almost completely eliminate the harmful effects of the number of factors, such as chemical factors, dust, microclimate parameters and the severity of the labor process.

Conclusion. Assessment of occupational risks of employees of hazardous industries is undoubtedly one of the key elements of the enterprise's OHSAS. The correctness of this assessment allows you to identify jobs with unfavorable working conditions in time, preventing the occurrence of accidents among employees. In this study, using the results of the risk assessment of specific jobs, the collective risk of an entire division of the enterprise is determined, on the basis of which the most at-risk profession is identified. Corrective engineering measures aimed at protection from occupational risks are proposed for employees of this profession.

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Contribution of the authors:

V. V. Maslenskiy — formulation of the main concept, goals and objectives of the research, analysis of the research results, revision of the text, correction of conclusions; N. A. Lyubetskaya — calculations, preparation of the text, formulation of conclusions.

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Evaluation of the properties of anti-corrosion coatings of steel structures

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Introduction. The properties of an object with metal structures and the safety of its use depend on the environmental impact. This explains the urgency of the problem of universality of anticorrosive coatings.
Problem Statement. The main goal of the study is to find a new approach to choosing the most rational means of protecting metal structures from corrosion based on experimental data. This takes into account the possibility of obtaining fuzzy information on various evaluation criteria.
Theoretical Part. The main objectives of the study: the formation and justification of necessity of application of concepts (axioms) of sufficiency; analysis of the quality of anti-corrosion materials; constructing a measure for assessing (analyzing) the quality of facilities; evaluation (analysis) of quality of corrosion resistance in accordance with the concept of sufficiency.
Conclusion. The original approach to the problem of choosing the most rational means of protecting metal structures from corrosion is based on experimental data. The considered general methodology can be used for selecting criteria for evaluating the safety of metal structures, since it is based on proven decision-making methods.

Keywords: operational safety, risk minimization, uncertainty, decision theory, anti-corrosion coatings.

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Introduction. From the point of view of industrial safety, the issues of managing the technical condition of metal structures remain relevant. In this work, the atmospheric effect of water of different salinity, temperature etc. is considered as factors leading to corrosion. When operating a metal structure in unfavorable conditions, the load-bearing capacity and the level of strength, safety of the object are reduced, and operational qualities deteriorate. In this regard, the task of finding new approaches to protecting metal structures from destruction due to corrosion is urgent.

The purpose of the research is to develop a method for finding universal methods and means of anti-corrosion protection of metal structures based on the available database.

The originality of this approach lies in the fact that for the analysis of protective coatings, the authors of the presented study take into account fuzzy information. To assess the quality of coatings, an integral sufficiency indicator is used. It is assumed that its numerical value has a boundary value, the exceedance of which does not make sense at best, and at worst will lead to a negative change in the indicators not taken into account in this work. We will accept this statement as an axiom or concept of sufficiency.

The main objectives of the study: formation and justification of the need to apply the concept (axiom) of sufficiency; analysis of the quality of anticorrosive materials; development of a model for constructing an indicator for assessing (analyzing) the quality of objects; assessment (analysis) of the quality of anticorrosion resistance in accordance with the concept of sufficiency on the example of the selected coatings.

Problem Statement. Metal structures of mechanical objects are operated in various climatic conditions. They are affected by temperature, solar radiation, humidity, and water (including salt). Primers and two types of enamels (anticorrosive and coating) are proposed to consider as anticorrosive materials. These means can be used to process:

— pure metal,
— structures with strong protective coatings,
— structures with remnants of previously used materials.

The studied coatings have high indicators of the adhesion force of the product to the surface, anti-corrosion and aesthetic properties. The wear resistance of anticorrosive coatings (ACC) can be improved by changing the influence of

the parameters of mechanical interaction (for this purpose, the composition is applied to a wet surface) and the heat-reflecting effect in the infrared region of the spectrum [1-4].

For a comparative analysis of the most common anticorrosive materials, their physical and mechanical properties were studied in the laboratory.

In this study, the main indicators that determine the quality level of a protective anti-corrosion coating are considered: uniformity, flexibility, weather resistance, adhesion, thickness.

Adhesion of the coating (i.e., the strength of adhesion between the protected surface (substrate) and the anticorrosive material was controlled by the cross-cut test method.

Thickness of the dry coating on steel samples was controlled using MT-30N and Microtest devices.

Uniformity, which determines the protective properties of coatings, is the number of microcracks per square centimeter of the coating. It was checked by a DUK-60 M flaw detector.

Flexibility, that allows you to predict the behavior of coatings during operation, is the maximum amount of deflection of the sample. If it is exceeded, a macro-crack (main crack) is formed in the anticorrosive coating. This quality was checked using a special flexibility scale (FS).

Weather resistance is the ability of the material to maintain its physical and mechanical characteristics under the influence of various climatic factors [5-8].

In some cases, it is not obvious to take into account quality indicators, including data on their quantity, measurement method, and significance, from the point of view of multi-criteria assessment of technical condition. Of course, the list of criteria should include those that cover all the essential aspects of the objects under study.

In most cases, the quality assessment is based on some positive characteristics of the research object and assumes that the corresponding indicator should grow. However, this approach is impractical to use when assessing the technical condition. The input of an integral indicator is determined by the need to set the limit of the numerical value of the factors under consideration. The consequences of going beyond this limit, presumably, may be:

— it is not advisable to further increase the indicator,

— negative results due to changes in unrecorded indicators (that is, a decrease in the quality of the protective coating).

The described above approach is accepted as an axiom of sufficiency.

Theoretical Part. Quality analysis (assessment) has five stages.

1. Preliminary analysis: statement of the problem taking into account the elements that characterize the initial set of objects to be evaluated.

2. Structural analysis: formulation of the main goal of the assessment and the goals of subsequent levels, determining the possibility of achieving them.

3. Uncertainty analysis: search for unifying elements of the actual technical condition of the object and its place in one- and multidimensional factor spaces.

4. Utility or value analysis: placing points on the numeric axis that display a certain set of options for the object's state. In this case, each point is assigned the value "better — worse". This is how the criterion's usefulness is established.

5. The procedure of optimization: maximization of the expected utility, in particular, the search for solutions leading to the achievement of the required technical condition.

Methodological approaches to building the structure of goals and developing a list of criteria are described in [1]. We assume that for numerical evaluation, it does not matter which source array of objects is considered. At the same time, it is preferable to identify the best objects in terms of technical condition using a special integral indicator that gives a higher (or lower) rating from a mathematical and methodological point of view. The principles of selecting and evaluating objects based on their placement within a set of criteria are described in [2]. Thus, the approach considered here is not the only one. Its main element is the rule (or principle) of evaluating π, which defines the relation of a multiplicative metrized linear order on a set of partial criteria.

For a pair of objects a_ν and a_μ the choice will be based on the following principles:

— $a_\nu > a_\mu$ — the first object according to the considered factors is "better" than the second one,

— $a_\nu \sim a_\mu$ — the objects are equivalent,

— $a_\nu < a_\mu$ — the first object according to the considered factors is "worse" than the second one.

Pairs of objects are characterized by comparison vectors $S_{\nu\mu}$.

The principle of the generalized criteria and so-called lexicographic approaches with a strong preference for a set of particular criteria are useful for research. In this variant, the objects are equivalent ($a_\nu \sim a_\mu$), and their estimates correspond to the established minimum values [4].

Let us consider the condition

$$a_\nu \sim a_\mu \Leftrightarrow x_i^\nu \ge d_i,\; x_i^\mu \ge d_i, \quad i = 1, \ldots, m, \tag{1}$$

where d_i — the specified threshold value (sufficiency level); m — the number of indicators under consideration; $x_{i\nu}$ and $x_{i\mu}$ — the estimates of the compared objects (ν-th and μ-th).

We will consider the described condition as a mathematical formulation of the concept of sufficiency and apply it to assess the technical condition. However, the direct use of this quality assessment principle limits the possibility of its application in practice, since it assumes the presence of a strong preference relation on the set of criteria $K = \{K_1, K_2, \ldots, K_m\}$ in the form of:

$$K_1 \ge K_2 \ge K_3 \ge \ldots \ge K_m. \tag{2}$$

We conclude that it is more appropriate to set a metrized multiplicative relation of linear order, that is, to apply a generalized criterion.

In this case

$$a_\nu \succ a_\mu \Leftrightarrow \sum_{i=1}^{m} \alpha_i K_i(a_\nu) > \sum_{i=1}^{m} \alpha_i K_i(a_\mu);\;\; a_\nu \sim a_\mu \Leftrightarrow \sum_{i=1}^{m} \alpha_i K_i(a_\nu) = \sum_{i=1}^{m} \alpha_i K_i(a_\mu). \tag{3}$$

Here α_i — the coefficients that satisfy, for example, the condition

$$\sum_{i=1}^{m} \alpha_i = 1. \tag{4}$$

As a monotone operator for mapping (convolution) of the initial set of the evaluated objects to the numerical axis "better — worse", we can use the suggestions of the authors of works [5, 6]. In this case, the integral indicator will be a scalar linear function of the original criteria, defined by a blurred (according to Zadeh) relation on the pairs of specially defined objects.

Let us move on to the model for building an indicator for assessing (analyzing) the quality of objects. The task is to determine the vector component B, obeying the condition (4), and constructing the index z, approximating objectively known or specifically set (training) matrix of pairwise interactions between artificial objects (means of transport).

$$Q = \left\| q_{rk} \right\|_{p,p}. \tag{5}$$

Let us take p — as the amount of the artificial objects, which is determined by the size of the matrix Q; q_{rk} — the elements of the matrix; r, k — artificial objects on the number line of "better — worse".

On the z axis, the square of the distance between the *r-th* and *k-th* artificial objects (protection options) has the form:

$$d_{rk}(B) = (z_r - z_k)^2 = \left[\sum_{j=1}^{m} b_j (x_{rj} - x_{kj}) \right]^2, \tag{6}$$

$$D(B) = \left\| d_{rk} \right\|_{p,p}. \tag{7}$$

Matrix $D(B)$ is assessed using the functional

$$J(B)=\sum_{r=1}^{p-1}\sum_{k=r+1}^{p}[d_{rk}(B)-q_{rk}]^2\ . \qquad (8)$$

The required integral criterion is a function *Z** if *J(B)* is minimal and the vector *b* meets the specified conditions. The resulting indicator is used to assess the technical condition.

Here is an example of evaluating (analyzing) the quality of corrosion resistance of objects.

The ACC of the processed design will be "best" at the maximum level of sufficiency. The main task is to distribute the weight coefficients, that is, to assign a degree of significance to each indicator in comparison with the others [9, 10].

The following variant of modeling indicators is proposed for forming an assessment of the sufficiency of properties of anticorrosive agents (table 1).

Table 1

Modeling indicators for evaluating the sufficiency of properties of anticorrosive agents

Anticorrosive coating		Value of indicators			Unit of measurement
Parameter	Property	min, y_{0j}	max, y_{Mj}	sufficient, y_{tj}	
y_1, σ	Adhesion	10^{-2}	2	0.3	MPa
y_2, H	Thickness	1	100	30	um
y_3, S	Uniformity	0.2	50	20	1/sm^2
y_4, h	Flexibility	1	5	3	mm
y_7	Weather resistance	0.03	3	1.0	year

To evaluate anticorrosive materials, the indicators were modeled that characterize the adhesion of the coating, its thickness, continuity, flexibility, and weather resistance. The minimum, maximum, and sufficient values of indicators are taken from the database, which contains the data obtained during the maintenance and repair of real objects. The number of objects and indicators that characterize the automatic transmission parameters can increase or decrease.

Let us calculate the level of sufficiency z_i and determine the best of the analyzed ACC by ranking (table 2).

Table 2

Determination of the best anticorrosive coatings

No.	ACC name	Sufficiency indicator z_i	Place in the rating
1	Primer FL-03к	0.88	4–5
2	Primer EF-065	0.85	7
3	Primers VL-02 and VL-023	0.91	2
4	Primer MS-17	0.88	4–5
5	Enamel EP-46U	0.87	6
6	Enamel KhS-5226	0.9	3
7	Primer Tectyl BT Coat	0.92	1

The table shows that the best of the compared anticorrosive coatings is Tectyl BT Coat (the sufficiency index is 0.92). According to the indicator "corrosion resistance", the technical condition of the treated structure will be better taking into account the adhesion of the coating, its thickness, uniformity, flexibility and weather resistance. VL-02 and VL-023 primers (sufficiency index 0.91), as well as KhS-5226 enamel (sufficiency index 0.9) are also acceptable for use.

Conclusion. The developed method of searching for universal methods and means of anticorrosive protection of metal structures is based on the experimental data and assumes the possibility of processing fuzzy information. The considered methodology for constructing a criterion for evaluating the quality of anticorrosive coatings can be used to

build the required criteria for evaluating the safety of metal structures, since it is based on the proven decision-making methods.

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Contribution of the authors:

V. V. Deryushev — formulation of the main concept, goals and objectives of the research, development of an original approach to the problem of choosing the most rational means of protecting metal structures from corrosion based on experimental data, preparation of the text, correction of conclusions; M. M. Zaytseva — development of a model for constructing an indicator for evaluating (analyzing) the quality of objects, analysis of research results, formulation of research conclusions, correction of the text; E. E. Kosenko — practical application of the developed approach, solution to the problem of evaluating (analyzing) the quality of corrosion resistance of objects; S. K. Mamberger — search for examples for practical application of research results, revision of the text, formulation of conclusions.

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Investigation of the stability of polymer composites based on epoxy matrix and astralenes under exposure to high temperatures

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Introduction. The paper considers one of the ways to improve performance characteristics of products based on polymer composites with epoxy matrix by improving their thermal stability and durability by introducing modifiers.
Problem Statement. The objective of this study is to compare the heat resistance indicators of epoxy matrices of classical design with compositions improved by modification with carbon nanostructures.
Theoretical Part. For basic information, the selection of modifying materials, the selection of the optimal composition of the binder based on epoxy resin, low-molecular hardener, plasticizer and filler was carried out. The technology of introducing modifiers into the structure of the epoxy matrix was developed. Thermogravimetric and differential thermal studies were used to analyze changes in the temperature of the beginning and the end of the thermal effect, the temperature of the maximum thermal effect, the amplitude value and width of the peak effect, the index of its shape, and the mass loss of heated samples depending on their formulation.
Conclusion. The results of the study indicate the possibility of using epoxy resins filled with powdered carbon nanostructures in various areas of production due to the positive effect of additives on thermal stability indicators.

Keywords: epoxy resin, polymer composite material, thermal analysis, carbon nanostructures, astralen, fire safety, thermal stability.

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Introduction. In modern conditions, composite materials (composites) are considered one of the most promising and most popular materials. Their wide distribution is largely due to the ability to predict the required properties even at the development stage by modifying the composition and manufacturing technology of products. Polymer composite materials (PCM) occupy a separate niche of composites. In their structure, an organic polymer is used as at least one continuous phase. This can be, for example, polyester, epoxy, or organosilicon resin [1].

The structure of structural PCM includes a matrix (polymer binder) and one or more reinforcing fillers that give the material high strength. The composite components are selected in such a way that their mutual dissolution or absorption does not occur. Due to the specified adhesive bond between the matrix and the filler, some essential qualities of the PCM are provided, including solidity. You can change the adhesive properties by selecting and modifying the matrix composition.

One of the most common binders is epoxy. The basis of the epoxy matrix is epoxy resin (ER). The epoxy matrix of the composite is obtained by introducing functional additives into the resin: hardeners, thickeners, etc. ER is a liquid and viscous or solid transparent thermoplastic structure that has a shade from light to dark brown. Cured epoxy polymers are quite fragile matrices with low fire resistance, so various methods of their modification are widely used. When hardeners are added to epoxy resins, thermosetting materials are formed that have high adhesion and cohesion; good dielectric properties; increased mechanical strength, as well as resistance to water and many chemical compounds [2]. However, significant disadvantages that limit the use of such single-phase materials are low thermal stability and stability when exposed to elevated temperatures [3].

To increase the thermal stability, it is proposed to reinforce the epoxy matrix with astralenes (Astr), which are carbon nanostructures. The paper analyzes the formulation of the modified composition and the method of complex introduction of a low-molecular hardener and nanoparticles into the ER.

Due to the binding of the molecules of the components of epoxy matrices with carbon nanostructures and due to their antioxidant properties, the strength characteristics and thermal stability of materials are increased. This, in turn, leads to an increase in the energy required for the destruction of the structured sample, which makes it possible to slow down the destruction processes in the matrix. Obtaining experimental confirmation of increasing the thermal stability of PCM by introducing Astr will allow us to draw conclusions about the possibility of using this filler as a nanomodifier in practice.

Problem Statement. The purpose of this study is to compare the heat resistance of epoxy matrices with compositions improved by modification with carbon nanostructures. At the same time, it is necessary to evaluate the possibility of using epoxy resins in various areas of production due to the positive effect of additives on thermal

stability indicators. It is necessary to select modifying materials, as well as the optimal composition of the binder based on epoxy resin, while it is necessary to develop the technology for introducing modifiers into the matrix structure. Based on these results, several criteria identified during the study should be analyzed.

Theoretical Part. The objects of the study were the characteristics of heat resistance of samples of a binder consisting of ED-20 epoxy resin [4], a hardener — triethylenetetramine (TETA) [5] and a plasticizer — diglycidyl ether of diethylene glycol DEG-1 [6], as well as samples of PCM based on this binder and powdered nanoscale fillers — astralens. According to [7], astralenes are polyhedral structures made of carbon atoms in the form of multi-layer particles with dimensions of 15-150 nm. The advantages of innovative Astr additives in comparison with nanoparticles of other elements are associated with high characteristics of conductivity, heat resistance, stability, and strength [8].

The mass concentration of the material components should be carefully selected taking into account the recommendations [9], since otherwise the performance characteristics may decrease, as well as the migration of molecules to the surface of the cured sample may be observed. Table 1 shows the formulation of materials selected according to the recommendations. Further preparation of samples of the modified material was carried out in several stages. It is known [10] that it is possible to ensure the quality of the fillers introduced into the matrix volume due to their dispersion in a low-molecular hardener using an ultrasonic bath followed by the addition of resin.

Table1

Formulation of the studied materials

Ingredients	Content by weight, %					
Epoxy resin ED-20	90	90	90	85	85	85
Hardener TETA	10	9	8	10	9	8
Pasticizer DEG-1	–	–	–	5	5	5
Filler Astr	–	1	2	–	1	2

At the first stage of the modified samples creation, the suspensions were prepared based on the hardener with the addition of carbon nanostructures and their subsequent dispersion at a temperature of 20.0±0.2 ºC and normal atmospheric pressure under the influence of an ultrasound source of 1 kW with a frequency of 60 kHz for 10 minutes. At the same time, homogeneous suspensions of epoxy resin with a plasticizer were prepared to obtain plasticized samples. Further, the modified hardener solutions were added to the pre-suspended resin to obtain compositions with element concentrations corresponding to table 1. After that, the mixture was stirred for 5 minutes until it became homogeneous. At the next stage, the compositions were cured at room temperature. Fig. 1 shows the obtained samples of the studied materials.

a) *b*) *c*) *d*) *e*) *f*)

Fig. 1. Photos of samples with the formulations indicated in table 1:
a — without plasticizer and Astr; b — without plasticizer and with 1 % of Astr;
c — without plasticizer and with 2 % of Astr; d — with plasticizer and without Astr; e — with plasticizer and 1% of Astr;
f — with plasticizer and 2 % of Astr

To evaluate the behavior of the materials under study under thermal influence, their thermal effect indicators were determined at the "Termoscan-2" installation. The method of thermal analysis [11] is used, based on the study of the properties of substances and the processes occurring in them when the temperature changes. Two variants of this analysis are traditionally used: thermogravimetric (TGA) and differential thermal (DTA).

The essence of differential thermal analysis is to register the thermal effects that accompany physical transformations and chemical reactions under the influence of high temperatures [12]. The method is based on changing the fundamental features of substances related to their chemical composition and crystal structure.

The analysis of the heating process of the material under study on thermograms of differential thermal analysis, called DTG curves (Fig. 1, 2), indicates the presence of several peaks corresponding to the thermal effect (TE) of the components of materials with the formulation corresponding to table 1. All samples have two characteristic peaks indicating intensive oxidation followed by dissociation of Triethylenetetramine — the first (low-temperature) peak and epichlorohydrin — the second (high-temperature) peak.

The main indicators of TE in differential thermal analysis are:

— start temperature — the temperature at which intensive oxidation of the substance begins;

— maximum temperature — the temperature at which self-ignition occurs, and the oxidation process is replaced by dissociation processes — chemical and physical decomposition of the oxidized component;

— end temperature — the end temperature of the component dissociation process;

— amplitude value — temperature change (Delta) from the beginning of the TE to its maximum value;

— peak width — the temperature range during which the TE was observed;

— shape index — describes the ratio of the duration of dissociation and oxidation processes.

Table 2 shows the values of indicators describing the processes of burnout of the components of the studied samples without a plasticizer.

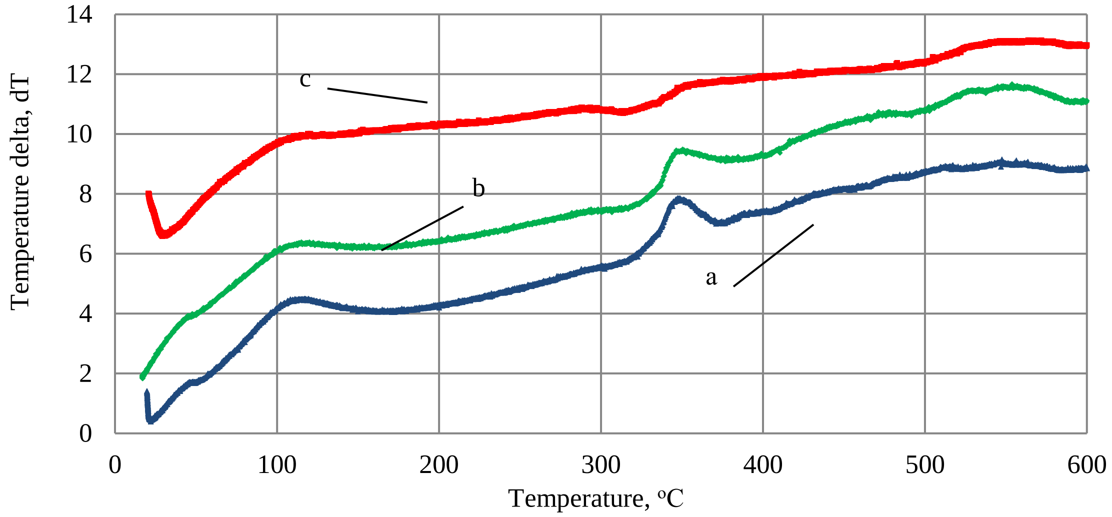

Fig. 2. Differential-thermal curves of materials without plasticizer:
a — without Astr; b — with 1% of Astr; c — with 2% of Astr

Table 2

Parameters of differential-thermal curves of materials without plasticizer [1]

Temperature indicators, °C, and TE shape index	Parameter values for material formulations					
	without Astr		with 1% of Astr		with 2% of Astr	
	Peak 1	Peak 2	Peak 1	Peak 2	Peak 1	Peak 2
Start temperature	51	315	48	313	not observed	317
Maximum temperature	115	351	118	353		562
End temperature	170	375	151	377		*
Amplitude value	2.78	2.2	2.37	1.88		2.33
Peak width	119	60	103	64		>317
Shape index	0.86	0.67	0.47	0.6		-

[1]Note — no exothermic reactions are observed before 600 °C

The comparison of the indicators of thermal analysis of materials without plasticizer allows us to draw the following conclusions:

1. For a sample with an Astr filler at a concentration of 2 %, the 1st TE peak is not observed during heating, indicating intensive destruction of the hardener components. The beginning of the peak of the other component begins at a temperature similar to the temperature of the beginning of the TE of the sample without fillers, but the ignition temperature shifts by about 200 °C, and when the sample is further heated to 600 °C, exothermic reactions do not stop.

2. The rate of oxidation of the modified sample is lower than the rate of volatilization of thermal decomposition products, which indicates an increase in the thermal stability of the material by increasing the oxidation time from the beginning to its transition to the self-ignition process.

3. Peak value of the TE material with the addition of 1 % of Astr is lower than the values for the sample without filler (control sample), indicating the decrease of intensity of the exothermic reactions and is also the proof of the increasing thermal stability of the modified composition compared with the unmodified one.

4. The presence of bright peaks with a gentle deviation of the descending branch on the thermogram indicates the effects of crystal lattice destruction occurring in the structure, which, however, is not observed for a sample with a 2% of Astr content.

The materials with the addition of a plasticizer behave somewhat differently (fig. 3). The results of these studies are shown in figure 3 and table 3.

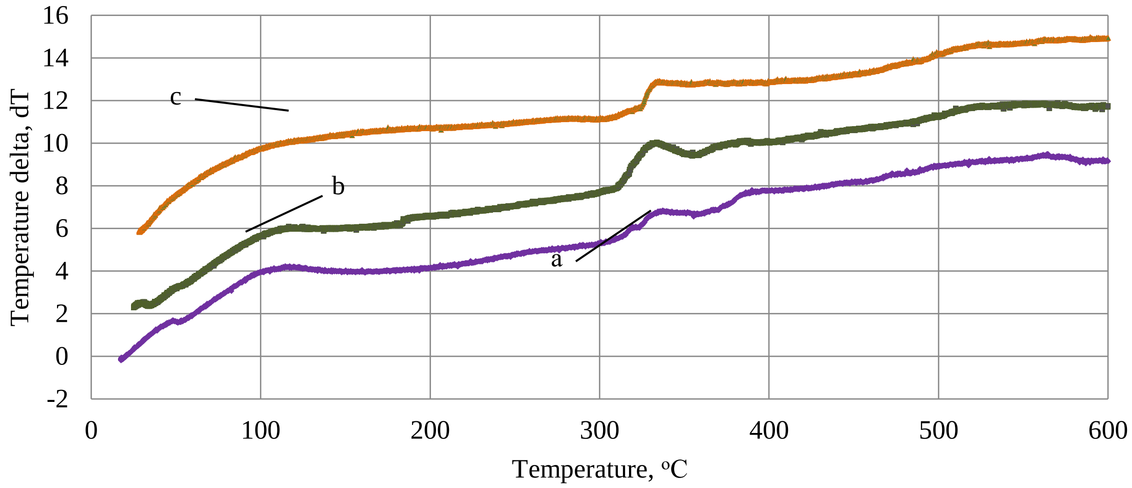

Fig. 3. Differential-thermal curves of materials with plasticizer: a — without Astr; b — with 1 % of Astr; c — with 2 % of Astr

Table 3

Parameters of the differential-thermal curves of the materials with plasticizer

Temperature indicators, °C, and TE shape index	Parameter values for material formulations					
	without Astr		with 1 % of Astr		with 2 % ofnAstr	
	Peak1	Peak 2	Peak 1	Peak 2	Peak 1	Peak 2
Start temperature	50	305	56	311	not observed	*
Maximum temperature	111	336	116	334		
End temperature	136	355	138	357		
Amplitude value	2.48	1.41	2.73	2.08		
Peak width	86	50	82	46		
Shape index	0.41	0.61	0.37	1.00		

* — there is only the beginning of the thermal effect at 321 °C with a slight inflection when the temperature reaches 332 °C..

When comparing the results of the analysis of the control sample and the sample with the addition of plasticizer, a decrease in all 6 indicators of DTA, indicating the increase of flammability, increasing the rate of oxidation and burn-out material, and, as a consequence, the decrease in the combustion stability when included in the resin composition of the plasticizer on the basis of diglycidylether ether of diethylene glycol. This phenomenon is primarily due to the dilution of epichlorohydrin, the self-ignition temperature of which exceeds 400 °C, with more combustible diethylene glycol with a self-ignition temperature of 210 °C [13]. This problem can be solved by using plasticizing compounds with higher thermal protection properties [14]. The comparison of the DTA indicators of materials with the plasticizer allows us to draw the following conclusions:

1. For a plasticized material sample with 2% of Astr, the TE peak is not observed, as in the case of non-plasticized material.

2. There is a significant shift and smoothing of the second characteristic peak of the TE. So, for it, only the beginning of the thermal effect is observed at 321 °C with a slight inflection when the temperature reaches 332 °C. The temperature of the maximum TE, as well as the temperature of its end, is observed when heated above 600 °C. This flat shape and elongation of exothermic effects is characteristic of slow-moving oxidation processes, i.e. the formation of a coke layer with subsequent burning and volatilization of coke.

3. There were no significant changes for the better affecting the flammability of the material with the plasticizer when adding 1% of Astr.

The data obtained during the DTA indicate a significant improvement in the thermal stability of the epoxy resin, in the structure of which there are Astr nanoparticles of 2% by weight. This effect is observed due to the antioxidant properties of modifiers, which inhibit the destructive processes of oxidation by increasing the energy required for the destruction of the sample structured by nanomodifiers.

Study of samples thermolysis by thermogravimetric analysis method. Thermogravimetric (thermal weight) analysis is based on obtaining and studying the regularities of changes in the weight of a substance during heating [15]. Thermogravimetric (TG) curve shows the change in the absolute or relative mass of a substance from the beginning to the end of heating. It is also called a normal or integral thermal weight curve.

The processes occurring in a substance during heating can be interpreted most fully only in a combination of TGA and DTA data by obtaining the corresponding curves. For example, physical and chemical reactions of dissociation and dehydration, such as evaporation of moisture, volatilization of carbon dioxide and other volatile components are accompanied by mass loss. The reverse process is an increase in mass; it is caused by oxidation and the formation of a carbonized carbon layer on the surface of products. During heating, a number of oxidation and carbonation transitions in the dissociation reaction can occur in the sample. Also, there may be several peaks on the TG curves, which indicate the destruction of the moisture contained in the sample, the surface fat layer, unpolymerized molecules, and other impurities in the material.

The main characteristics of the TG curve are the decomposition start temperature and the reaction end temperature corresponding to the maximum mass change. The pronounced peaks of the TG curves mean acceleration of thermal decomposition processes, and, as a result, an increase in the rate of mass loss. In practice, we can trace the relationship between TG curves and DTG curves due to the fact that strong TE leads to the accelerated growth of the carbon layer with its further intensive decomposition (fig. 4-9).

When analyzing the process of mass loss of samples of the materials under consideration, the following is observed:

1. There is a gradual oxidation of the control sample material when heated up to 375 °C, but when this temperature is reached, equal to the temperature of the end of the TE, the continuous destruction of the sample occurs.

2. The loss of mass of the plasticized sample without adding fillers has several differences. First, the curve is more uniform, which indicates a stable rhythm of the processes of mass change. Secondly, at 180 °C, there is a transition from mass build-up to its volatilization. On the DTG curves at this temperature, a smooth increase in TE is observed. A slight loss of mass during this process, observed on the TG curve, allows us to judge the volatilization of the burnt surface layer, which is accompanied by a decrease in the thermal insulation capacity of the sample surface undergoing destruction. The end of thermal decomposition of the material is observed at 355 °C, which correlates with the temperature of the end of the TE obtained by analyzing the DTG curve.

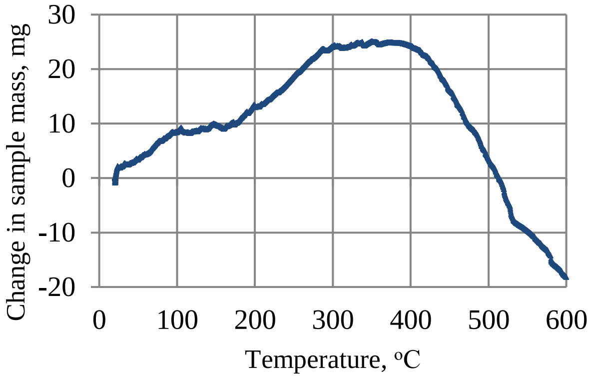

Fig. 4. Thermogravimetric curve of the control sample

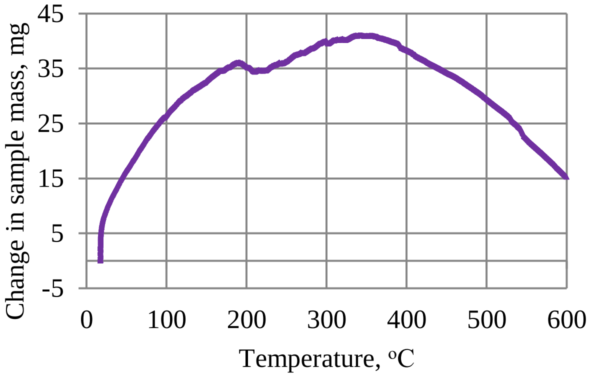

Fig. 5. Thermogravimetric curve of the sample without Astr and with plasticizer

3. For a nanofilled sample with 1 % of Astr, the first transition from mass gain to mass loss is observed at 237 °C, but in the temperature range of 289-332 °C, the change in the mass of the sample is not observed, or is insignificant. When 332 °C is reached, the process of material destruction begins. However, comparing the TG and DTG curves, it is possible to notice that the mass loss of the sample begins before the maximum TE is reached. This is also due to the loss of the heat-insulating layer due to the volatilization of compounds that have been oxidized during heating.

4. The mass gain of a nanofilled plasticized sample containing 1% of Astr occurs when heated above 50 °C up to a temperature of 600 °C. Otherwise, the TG curve is close to a linear one with a slight change in the angle of inclination, corresponding to a change in the rate of mass gain, when heated to temperatures of 180, 354 and 442 °C. In this case, the temperature at which the maximum deviation from the previously recorded angle of inclination is observed coincides with the temperature of the end of the TE. This indicates an increase in the duration of volatilization and the decrease in the intensity of dissociation.

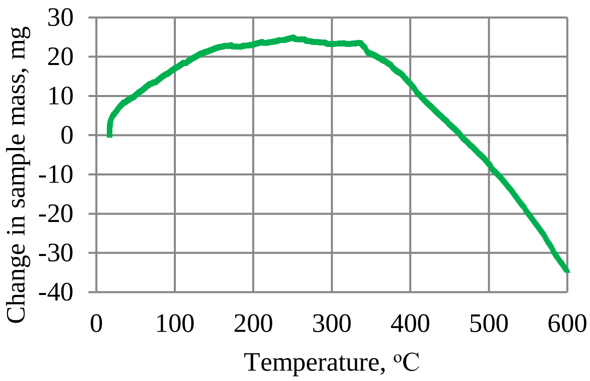

Fig. 6. Thermogravimetric curve of the sample with 1% of Astr

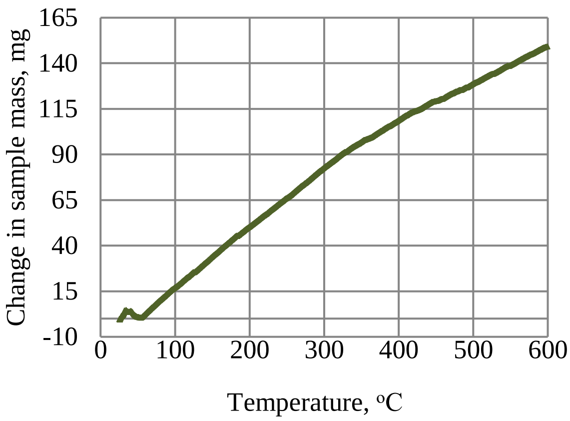

Fig. 7. Thermogravimetric curve of the sample with thea plasticizer and 1% of Astr

5. A sample with 2 % of Astr is characterized by the presence of small peaks corresponding to short dissociation sections with a heating of no more than 10-15°C. The beginning of such sections is observed at temperatures of 56, 140, 281, 305, 458 and 545°C. In addition, the heating of the sample is not accompanied by the end of the destruction due to the fact that the change in mass is in the nature of an increase. These observations indicate that the thermal decomposition of the sample does not occur when heated to 600 °C. A large number of small peaks indicates an uneven loss of volatile components, and the short duration of their dissociation indicates the ability of the material to build up a heat-insulating carbon layer.

6. The plasticized material containing 2% of Astr also shows only the process of mass gain and confirms the absence of TE when the sample is heated up to 600 °C. Moreover, when heated above 245 °C, the increase in mass takes a linear character, that is, it becomes as stable as possible.

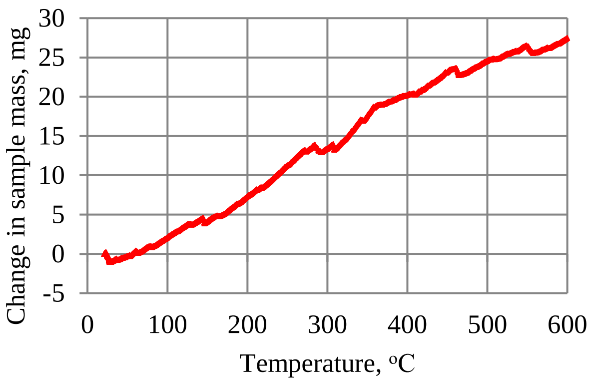

Fig. 8. Thermogravimetric curve of the sample with 2% of Astr

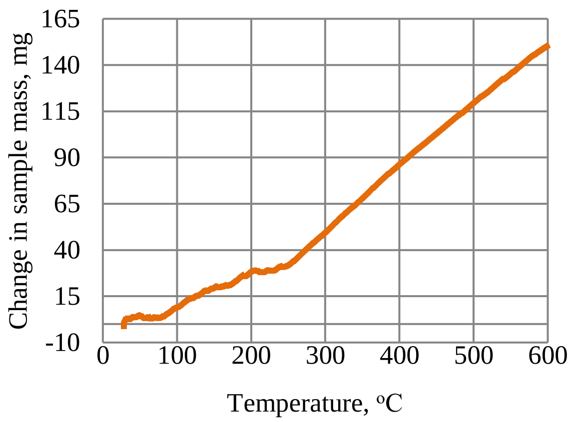

Fig. 9. Thermogravimetric curve of the sample with a plasticizer and 2% of Astr

Thus, it can be observed that for samples that include a plasticizing agent, the TG curves are smoothed, which indicates the stabilization of the heating process. Samples containing 2% of Astr nanoparticles are characterized by the absence of thermal decomposition, which is accompanied by the mass loss. This fact is also associated with the build-up of the carbonized layer on the sample surface. This makes it possible to strengthen the thermal insulation of the material and limit the access of the oxidizer, which is an accompanying protective mechanism during the combustion of polymers. It is also worth noting that the nature of the mass loss of the plasticized samples is close to linear. This is primarily due to the fact that the plasticizer reduces the probability of cracking and reduces the number of defects in the sample volume, which also has a positive effect on the material's resistance to high temperatures.

Conclusion.

1. Due to the strength characteristics and reinforcing properties of Astr, which make it possible to cross-link structural defects of the modified material, for samples with 2% of Astr, there are no peaks of thermal effect on the DTG curves, that is, when the material is heated up to 600 °C, the crystal lattice is not destroyed.

2. When the Astr modifier with the pronounced antioxidant properties is introduced into the material structure, the oxidation process is inhibited. The increase in the duration of oxidation contributes to the formation of a carbonized layer that contributes to thermal protection and insulation.

3. Due to their small size, Astr particles have a large specific surface area, which determines their high sorption properties. This reduces the amplitude value of the thermal effect and, consequently, the intensity of exothermic reactions for samples containing 1 % of Astr.

4. The addition of Astr with the plasticizer makes it possible to achieve a uniform, close to linear change in the mass of the sample, which indicates the stable nature of heating and oxidation processes. This also contributes to the stable formation of a heat-protective and insulating carbonized layer.

5. A large number of small peaks of mass change on the TG curves of the sample without a plasticizer indicate uneven dissociation of components, which also contributes to the build-up of the carbon layer with regular updating.

The results obtained make it possible to specify and supplement theoretical data on the behavior of epoxy materials modified with carbon nanostructures at elevated temperatures, and also to demonstrate the positive effect of modification on thermal characteristics of the PCM of the proposed composition. The synergistic properties of the modifiers lead to an increase in the thermal stability of the material compared to the base polymer composition. The use of modified material will improve the performance of heat resistance and strength of composite products under the influence of elevated temperatures during a fire.

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Improving safety and reliability of Gazelle series vehicles by upgrading frame structures

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Introduction. The cargo frame is a load-bearing element of the car, since the body and chassis are installed on it. Therefore, high strength requirements are imposed on this node. For safe and reliable operation of the truck, the frame must be adjusted and balanced, since even minor changes in the geometry can negatively affect the overall condition and safe operation of the equipment. This article discusses methods for lengthening the load-bearing elements of trucks on the example of a light-duty car "GAZelle".

Problem Statement. Car frame extension is a high-tech process that requires high precision, knowledge, and the use of a wide range of equipment. The extended frame adds a number of advantages to the car, which in turn makes it possible to transport cargo with larger dimensions. The main goal of this work is to enable the car to transport bulky cargo. Also, in the process of extending the frame, it is checked for cracks, breaks and corrosion foci and, if necessary, repairs are made, which increases the reliability, safety and service life of the entire structure as a whole.

Theoretical Part. When extending the standard support, all attachments are removed from the car: fuel tanks, body, transmission, drive shaft. All that remains is the cab, the bridge, and the engine. Then the frame is cut in three places. Two cuts are made at a distance of 80 cm in the direction from the cab to the rear bridge, and the last one is made at a distance of 40 cm from the rear bridge in the direction of the rear overhang. Then a longer channel is installed on the frame. It is secured with rivets, bolts, or lap welding. After that, the structure is assembled back. This takes into account the redistribution of loads and the need for high-quality performance of all types of work.

Conclusion. The frame is an integral part of not only trucks, but also an important component of passenger cars, as well as light-duty vehicles. Its technical condition is just as important as the condition of, for example, the braking system, as it also ensures the safety of both the driver and pedestrians. The lengthening of the frame in the conditions of repair and mechanical enterprises allows you to increase the load capacity of serial cars of the GAZelle series while ensuring their reliability and safety.

Keywords: safety, reliability, load-bearing elements, car frame, welding joint, strength, load capacity, durability.

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Introduction. The car frame is the basic element that takes the load transmitted to the suspension. It is designed for mounting the main units and mechanisms. Cars with a short frame are in less demand than cars with an extended design of this basic part. Since most cargo transportation is designed for large-sized cargo, there is a need for cars with a longer body. Many of these needs are not met by manufacturers, so extending the frame in repair companies is the best technical solution.

The designs of such units can be divided into two types. The first is in the form of an elongated car body, used for passenger cars. The second — in the production of frame machines that transport bulky cargo. There are several types of car frames: ladder frame, backbone frame, fork-backbone frame and tubular frame. The advantages of such structures include uniform load distribution at road obstacles, ease of assembly, repair and maintenance of such vehicles, and increased passive safety [1].

The main goal of this work is to improve the operational capabilities of the car, as well as to increase the reliability and safety of the structure by lengthening the serial small-sized frame. The frame is the most important part of the car, so high quality is required when upgrading it.

The lengthening of the frame does not lead to an increase in its load capacity, so interference with other vehicle systems (chassis, brake system, springs, and wheels) is not required, and the safety and reliability of these systems are preserved. The upgraded frame will allow you to install a longer body on it, as a result of which the car will be able to transport large loads [2].

During the lengthening process, the geometry is maintained, all threaded connections are checked for integrity, and welded joints are subjected to thermal and mechanical treatment. The complex of these measures significantly increases the reliability and safety of the car as a whole.

Problem Statement. On many light trucks, the body is a supporting structure. It combines a number of powerful side panels that transmit the entire load. But on Russian cars of the GAZelle series, the load goes to the frame. In the last century, passenger cars designed on a frame were very popular. This was a classic assembly configuration [3]. But over time, the popularity of cars mounted on a load-bearing frame decreased due to the increase in the cost of such structures. Currently, only some SUVs and commercial vehicles with a load capacity of one and a half tons or more are equipped with frames. In this article, the modernization of frames is considered in relation to cars of the GAZelle series, the characteristics of which are shown in table 1.

Table 1

Characteristics of GAZelle cars

Car model	Capacity, kg	Basic frame length, mm	Car weight, kg	Wheelbase, mm	Rear overhang, mm
GAZ 3302-216	1500	4800	2980	2900	1580
GAZelle NEXT	1700	4920	3400	3145	1670
GAZ 33023	1800	4800	3200	2900	1550

Figure 1 shows a general view of the frame of the GAZelle car. It is made of thick-walled steel and combines two longitudinal channels. To give the structure rigidity, especially for torque effects, it has transverse elements made of pipe. In addition, the frame has two subframes. The first is for engine safety; the second contains rubber buffers and serves to support the gearbox [4]. Buffers are designed to dampen vibrations that are transmitted to the frame and body during vehicle operation. The frame design includes a suspension for the power take-off shaft. The frame has holes that serve to fix the interior on rubber shock absorbers, fixing the fuel tank, brake lines and other suspension elements. A wooden beam is placed as a buffer between the frame and the bottom of the cab body. It effectively dampens the impact that occurs when driving on uneven roads, and also does not allow the body to move on the surface of the frame. Otherwise, the body will wear out quickly [5].

Fig. 1. General view of the frame of the GAZelle car

Let us consider the structure of the standard frame (Fig. 2), which is installed on the GAZelle since 1994. The most loaded elements of the frame are the frame rails 5 and 17, connected by crossbars 1, 3, 7, 8, 11, 12, 14, 15. Fastenings of crossbars, especially with the use of angle braces 9 and 10, provide rigidity of the structure. The rear crossbar is provided with a brace 13. There are brackets 2, 4, 6, 18-22 on the frame to mount car components: power unit, front suspension, shock absorber, radiator, and buffer. The equalizing beam suspension supporting bracket is provided with a gasket 16.

Frame length is 4.84 m; width is 1.12 m;height is 0.29 m; and weight is 128 kg. The frame is designed for installation of a three-seat cab and a three-meter body. The maximum length of the body superstructure is 3.2 m. However, most car owners ignore the last parameter and install a 3.5-meter body on the frame without extending it. As a result, a longer body forms an additional load not only on the frame, but also on the car as a whole, the load on the rear axle increases, the car becomes less stable and safe on the road, and the car's maneuverability decreases [6]. To install a 4-meter body, you should install the factory frame with a length of 5.85 m.

Theoretical Part. The principle of lengthening a short standard frame is quite simple. All attachments are removed from the vehicle: tanks, body, gearbox, and driveshaft. All that remains is the cab, the bridge, and the engine. Then the frame is cut in three places (Fig. 3). Two cuts are made between the rear axle and the cab, and the last one is made in the rear of the frame. Then the lengthening channel is fixed to the frame using rivets, bolts, or lap welding. After that, the gearbox, fuel tanks, and specially extended driveshaft are re-installed [7].

Figure 4 shows the frame of the GAZelle NEXT car after its extension. The most appropriate solution is to upgrade the factory frame. Its width and length remain unchanged, and the thickness of the spars increases. The essence of the reinforcement is to install additional rolling profiles on the factory element. Various types of compounds can be used [8].

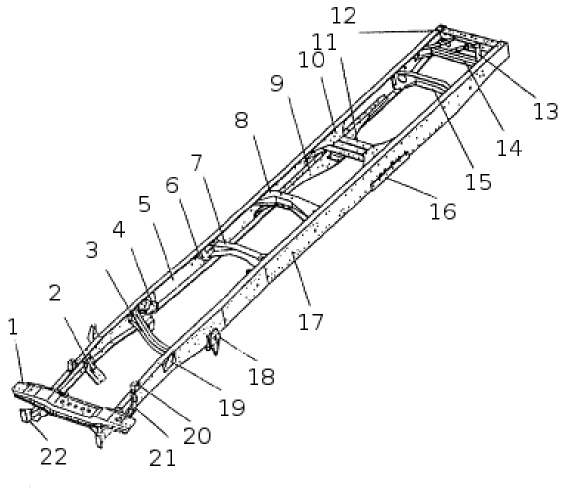

Fig. 2. Frame structure of the GAZelle car

Fig. 3. Places, where the frame of the GAZelle NEXT car is cut

Fig. 4. Lengthened frame of the GAZelle NEXT car

Often, one of the most common causes of frame deformation is the following errors in its design:

— steel grade mismatch to vehicle operating loads;

— plant savings on additional materials that strengthen the frame structure;

— mismatch of the thickness of the structural elements of the frame (spars, traverses, belts, etc.) to the working loads.

The usual GAZelle car, for example, GAZ 3302-216, has a load capacity of one and a half tons. The purpose of reinforcing the frame is to increase this parameter. Car owners expect that the GAZelle will be able to carry 2.5 or more tons, while the frame will withstand such a load. However, it is necessary to take into account the load-bearing capacity of other elements, especially the rear axle, suspension and clutch. The standard gearbox of the GAZ 3110 car, which is installed on the GAZelle, is not designed for the increased load capacity. The clutch disc may also fail in this case. In this situation, the transmission wears out, the bridge is overloaded, and the wheels fail when driving with obstacles. From this we can conclude that even with a reinforced frame the GAZelle is not able to carry more than specified in the manufacturer's specification. This is also confirmed by the fact that on the extended industrial versions of the car, the standard load capacity is 100-150 kg less than for conventional structures, since the lengthening of the body increases the vehicle's own weight. Therefore, lengthening the frame by welding is a dubious choice, and if you transport loads, they are light and bulky. The customer pays a significant surcharge for the transportation of high-volume cargo. Often, the extended GAZelle accepts cargo of the foam type at 5-ton tariffs.

Conclusion. The frame is an important part of not only trucks, but also passenger cars. Its technical condition is just as important as the condition of, for example, the braking system, as it determines the safety of both the driver and pedestrians. Now it is becoming more and more relevant to strengthen and lengthen the frames of trucks. The principle of lengthening a standard frame is quite simple. All attachments are removed from the vehicle: tanks, body,

gearbox, driveshaft, etc. All that remains is the cab, the bridge, and the engine. Then the frame is cut in three places and a lengthening channel is installed. However, its installation is accompanied by welding or the use of additional fastening elements. It should be noted that such units can be attributed to stress concentrators, so, when performing such work, due attention should be paid to the strengthening of these units.

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Aspects of application of a risk-based approach to hazardous production facilities

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Introduction. The paper considers the application of a risk-based approach to improving the level of safety of hazardous production facilities. The presented approach ensures optimal use of labor, material and financial resources, contributes to greater efficiency of state control and supervision bodies.
Problem Statement. The analysis of the state of HPF industrial safety showed the need to change the principles of assessing the state and monitoring the compliance with industrial safety requirements. Reasonable methods should be used to adequately assess the safety of facilities and the frequency and validity of inspections.
Theoretical Part. The use of modern tools for monitoring, collecting and storing information on the state of industrial safety will allow supervisory authorities to plan inspections of hazardous production facilities taking into account their actual condition. This can significantly reduce the administrative burden on businesses.
Conclusions. The use of a risk-based approach in planning inspections will ensure a higher level of industrial safety without involving additional resources of regulatory authorities.

Keywords: hazardous production facility, HPF, industrial safety, hazard classes, risk-oriented approach.

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Introduction. The level of safety of hazardous production facilities on the territory of Russia is determined by many factors. Among them there are personal interest of owners and operating organizations in ensuring safety, trouble-free operation of equipment, technical devices, the condition of buildings and structures, in creating jobs that meet safety requirements, attracting qualified specialists, and so on.

Problem Statement. Problems of industrial safety, equipment wear and maintenance of an adequate level of industrial safety are reflected in Decree of the President of the Russian Federation dated 06.05.2018 No. 198 "On the state policy of the Russian Federation in the field of industrial safety up to 2025 and beyond"[1].

It should be noted, that the level of safety at the HPF is steadily increasing, and the number of accidents and fatal injuries is decreasing[2]. At the same time, the catastrophic condition of the equipment and technical devices used at the HPF is recorded: 60-70 % of them have fulfilled the standard service life, and in this situation, the annual damage from accidents can reach 600-700 billion rubles.

The data from reports on the activities of the Federal Environmental, Industrial and Nuclear Supervision Service of Russia [3] allow us to generalize the causes of accidents and injuries at the HPF:

— incorrect design decisions or lack of them,
— wear and tear of technical devices, equipment, buildings, structures,
— untimely maintenance and repair of technical devices,
— low level of qualification of managers, responsible performers, maintenance and repair personnel,
— erroneous decisions and actions,
— violation of industrial safety requirements.

[1] Decree of the President of the Russian Federation dated 06.05.2018 No. 198 "On the fundamentals of the state policy of the Russian Federation in the field of industrial safety for the period up to 2025 and beyond". Collection of Legislative Acts of the Russian Federation. 14.05.2018, No. 20, article 2815.
[2] Ibid.
[3] Annual report on the activities of the Federal Environmental, Industrial and Nuclear Supervision Service of Russia in 2018. Rostekhnadzor. Available from: http://www.gosnadzor.ru/public/annual_reports/Годовой%20отчет%20за%202018%20год.pdf (Accessed 5th April 2020).

Theoretical Part. One of the tasks of the state policy in the field of industrial safety [4] — is to introduce a risk-based approach to the organization of federal state control and supervision in the field of industrial safety. A special law regulates this area[5], according to which the risk-based approach is a special method of organizing and implementing state control (supervision). In this case, the activities of a legal entity, individual entrepreneur, and (or) production facilities are assigned to a certain category of risk or a certain class (category) of danger. Depending on the category (class), the intensity (form, duration, frequency) of measures is selected for monitoring and preventing violations.

In order to optimize the use of labor, material and financial resources involved in the implementation of state control (supervision), reduction of costs of legal entities and individual entrepreneurs and improvement of the performance of state control (supervision), it is necessary to apply a risk-based approach.

Currently, HPFs are classified as one of four hazard classes [6], taking into account the potential risk of accidents and their consequences. As of December 29, 2018, according to Rostekhnadzor[7], there were registered in Russia:

— about 2 thousand objects of the I hazard class (extremely high),

— more than 7.7 thousand objects of the II hazard class (high),

— more than 89 thousand objects of the III hazard class (moderate),

— more than 70 thousand objects of the IV hazard class (low).

Statistics show that the main part of the recorded HPFs belongs to the III and IV hazard classes. Hazard classes correspond to the requirements of industrial safety included in supervisory activities. The control over the compliance with industrial safety requirements by owners and operating organizations determines the frequency of including a scheduled inspection in the annual plan starting from the day of the[8]:

a) decision to put a hazardous production facility into operation (taken in accordance with the procedure established by the government of the Russian Federation);

b) registration of a hazardous production facility in the state register of the HPFs;

c) end of the scheduled inspection.

Routine inspections of HPFs of the I or II hazard classes should be carried out no more than once a year, and of the III hazard class — no more than once every three years. HPFs of the IV hazard class are not regularly checked.

Unscheduled inspections are carried out only on complaints of organizations and people in connection with safety requirements violations, threats to life and health as a result of activities at the facility.

Thus, the attention of the Supervisory authorities to the HPF is not evenly distributed. At the same time, accidents continue to occur (destruction of technical devices and (or) structures, uncontrolled explosions or releases of dangerous substances[9]).

Special attention should be paid to the objects of the IV hazard class. Their exemption from periodic inspections led to the loss of information about the activities of such HPFs, the condition of buildings, structures, technical devices, technological processes, etc. The only source of information about HPFs is the report on production control of compliance with industrial safety requirements. HPFs that do not provide such reports become "invisible" to supervisors.

Issues of assigning a higher hazard class to individual HPF are periodically discussed. Appropriate decisions

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[4] Decree of the President of the Russian Federation No. 198 dated 06.05.2018.

[5] Federal law No. 294-FZ of 26.12.2008 (as amended on 01.04.2020) "On the protection of the rights of legal entities and individual entrepreneurs in the course of state control (supervision) and municipal control". State. Duma; Federation Council. Available from: http://www.consultant.ru/document/cons_doc_LAW_83079 (Accessed: 2nd April 2020).

[6] Federal law No. 116-FZ of 21.07.1997 (as amended on 29.07.2018) "On industrial safety of hazardous production facilities". State Duma of the Russian Federation. Available from http://www.consultant.ru/document/cons_doc_LAW_15234 (Accessed: 7th April 2020).

[7] Annual report on the activities of the Federal Environmental, Industrial and Nuclear Supervision Service of Russia in 2018.

[8] Federal law No. 116-FZ of 21.07.1997 (as amended on 29.07.2018).

[9] Federal law No. 116-FZ of 21.07.1997 (as amended on 29.07.2018).

are usually made in connection with frequent accidents. Therefore, in 2017-2018, due to a series of accidents during the operation of tower cranes, regulatory documents were amended [10], making the participation of Rostechnadzor obligatory in the decisions to put tower cranes into operation. The changes to the legislative documents on assigning the third and higher hazard class to HPFs operating tower cranes are considered. This will make it possible to carry out supervision on a scheduled basis [1-3].

When it comes to the need to organize scheduled inspections of HPFs, entrepreneurs, supervisors, and leading experts in the field of industrial safety disagree [4]. The government opposed the initiation of frequent inspections by the Supervisory authorities. There is still a discussion about the inadmissibility of a generalized approach to HPFs, even of the same hazard class.

The risk-based approach will allow the Supervisory authorities to individually consider a specific enterprise and its level of industrial safety, which will serve as the basis for planning inspections. Decree No. 198 mentioned earlier notes that one of the tasks of the state policy in the field of industrial safety is to "develop and implement information technologies that allow interaction with operating organizations, optimize the process of obtaining, storing and analyzing information on industrial control over the compliance with industrial safety requirements, on industrial safety management systems, on accidents and incidents at industrial facilities".

Information technologies are actively used in document management, including in the field of industrial safety [5, 6]. Submission of reporting documentation to the state authorities (in particular, reports on production control in the territorial department of Rostekhnadzor) allows you to define key performance indicators of compliance with the industrial safety requirements of a specific HPF [7-9], namely:

— signs of danger

— hazard class

— license,

— Industrial Safety Declaration,

— characteristics of technical devices and equipment (year of manufacture, number of owners, residual resource, technical inspection, repairs, unit replacement, examination of industrial safety, etc.)

— condition of buildings and structures (industrial safety expertise),

— contract for insurance of liability of the owner of a HPF for damage caused as a result of an accident,

— the company has special security specialists in the company's staff (name, education, advanced training, certification),

— the company has employees to manage, maintain and repair technical devices (name, education, clearance to work unsupervised).

Depending on the category of the HPF, its hazard class and types of activity, the list of information can be supplemented. A risk-based approach will allow you to:

1) distribute the workload of regulatory authorities more effectively,

2) focus on distressed businesses,

3) reduce the burden on bona fide enterprises (minimal risk of an accident),

4) adjust the number of checks depending on the data received.

[10] Order of Rostekhnadzor of 12.11.2013 No. 533 (as amended on 12.04.2016) "On approval of Federal norms and rules in the field of industrial safety "Safety rules for hazardous production facilities where lifting structures are used". Federal Environmental, Industrial and Nuclear Supervision Service of Russia. Available from: http://www.consultant.ru/document/cons_doc_LAW_157709 (Accessed 7th April 2020).

Conclusion. The use of a risk-based approach in the planning of inspections will ensure a higher level of industrial safety without involving additional resources of regulatory authorities. This approach will ensure constant monitoring of hazardous production facilities that do not comply with industrial safety requirements.

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Role of wastewater sludge treatment by anaerobic stabilization for Rostovvodokanal company

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Introduction. The article deals with the problems of treatment of organic sludge from the purification of municipal wastewater in Rostov-on-Don. To solve this problem, a method of anaerobic (methane) digestion of sewage sludge was proposed.

Problem Statement. The objective of this study is to determine the role of anaerobic stabilization for Rostovvodokanal company.

Theoretical Part. The differences between mesophilic and thermophilic modes of sediment digestion were determined, a technological line for preparing biogas for use was proposed. Calculations of the main parameters of the anaerobic digestion process in the digester have been made.

Conclusion. The results of the analysis showed that with the help of this modernization, the main problems are solved.

Keywords: anaerobic sludge digestion, sewage sludge, anaerobic stabilization, heated digestion tank, biogenic gas.

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Introduction. Rostov-on-Don is a large industrial city with a population over one million people, which leads to the formation of a huge amount of wastewater that is treated at the city's treatment facilities (Rostovvodokanal). In wastewater treatment technology, one of the most pressing environmental problems is the treatment and disposal of sludge. This is especially true for organic sludge of urban wastewater treatment. Until now, activated sludge waste is stored in the territories near the Rostov aeration station in Rostov-on-Don and is a real ecological and biological danger. According to the data of the Rostov aeration station (RAS), about 60-70 tons of compacted mixture of raw sludge and waste activated sludge with a dry matter humidity of 94-97% is formed per day, which leads to the need to increase the territories for silt detention ponds. The opportunities to increase this area are limited due to the rapid growth of the city and suburbs. At the moment, sewage sludge after the mechanical dewatering shop is first delivered to the silt sites for further dewatering, and then to the territories adjacent to the RAS. At the same time, it is noted that the activated sludge, having good adsorption characteristics, contains a large number of polluting components, including heavy metals, etc. Since sludge is not subjected to the disinfection process, it can serve as a source of not only chemical, but also microbiological contamination. According to the monitoring data, it was found that this sludge negatively affects the Don river water quality, since the storage areas are located on the shore. The degree of negative impact increases when it gets wet. Thus, sewage sludge is a sanitary and environmental problem of Rostov-on-Don that requires immediate solution.

Problem Statement. Sewage sludge is a separate type of waste. It makes about 1/3 of the total amount of production and consumption waste in large cities [1]. Permanent contamination of underground and surface waters and soils located on the territory occurs due to sludge storage at treatment facilities. The problem is the accumulation of huge amounts of sludge at silt detention ponds. To solve this problem, it is proposed to use anaerobic digestion of sewage sludge and waste activated sludge in order to reduce environmental pollution and use the entire volume of organic matter. During anaerobic digestion, we get biogas and decontaminated sediment.

Theoretical Part. Anaerobic digestion of sewage sludge. For processing and fermentation of sewage sludge, septic tanks, double-deck setting basins and sludge digesters are most often used. With small capacity, septic tanks are used, with the help of which the sludge is digested and the water is clarified. For settling of waste water, fermentation

and compaction of the sludge, double-deck setting basins are used. However, the most common are sludge digesters, which are used for sludge digestion with simultaneous heating and intensive mixing.

Sludge digester is a tank with a conical bottom without access to oxygen. They are used to produce biogas and decontaminate sediment. During fermentation, the chemical composition of sludge changes in the sludge digester. As a result, the ash content increases and the concentration of carbohydrates, fats, proteins decreases, and biogas is released.

Anaerobic stabilization can be performed in two temperature modes:

— mesophilic — from 30 to 38°C;

— thermophilic — from 50 to 60°C.

When comparing the two temperature modes, the following advantages of thermophilic fermentation were revealed [2, 3]:

— the required volume of the sludge digester is 2 times less;

— significantly less energy is spent on the anaerobic process;

— the total gas output is 2 times higher;

— sludge fermentation time is 3 times less;

— pathogenic microorganisms and helminths are completely destroyed;

— the unpleasant smell of sludge practically disappears;

— the dewatability of the stabilized sludge is much better.

The performance of anaerobic stabilization is determined by the chemical composition of the sludge, the degree of decomposition of organic matter, the mode of sludge loading and unloading, the mixing method, temperature, loading dose, volume and composition of biogas [4]. Biogas is produced by the breakdown of the main part of organic matter (proteins, fats and carbohydrates): fat — 60-65%; protein and carbohydrates — 40-35%. Therefore, more gas is obtained from the sludge of primary settling tanks due to the significant fat content. The breakdown rate increases with increasing temperature, but the temperature does not affect the breakdown limit. The residence time of the sludge and the amount of sludge loaded correlate with the temperature mode of fermentation. Due to inefficient mixing of the sludge in the sludge digester, the residence time of the sludge, the actual volume of the sludge digester, and the output of biogas are reduced. There goes the consumption of organic matter.

The production process of sewage sludge treatment is as follows:

— preliminary mechanical sludge thickening;

— anaerobic (methane) fermentation in sludge digesters;

— mechanical sludge dewatering;

— use of methane gas obtained in sludge digesters for the operation of a cogeneration plant (Block CHPP);

— burning of excess methane gas with a torch (flare) in emergency situations.

Use of biogas. The resulting biogas during anaerobic stabilization of sewage sludge has the following composition: methane — 55-70%; carbon dioxide — 27-45%; nitrogen and hydrogen sulfide — 3%; hydrogen — 1% [5]. In accordance with the composition of the biogas, it is necessary to carry out preliminary cleaning and drainage.

The biogas processing line consists of: a gravel filter; a cooler; an adsorber with zeolite; a compressor; gas engine generators, a gas tank and a gas combustion torch.

Biogas (methane) is fed to a gravel filter [5] designed for pre-dewatering and filtration (rough cleaning) of gas. Gas drying is carried out to protect and prevent rapid wear of gas cleaning equipment and gas pipelines [6]. For this purpose, a method is provided for cooling the gas to a temperature below the dew point in the heat exchanger with the removal of the condensed water, and the cooled gas is passed through the second heat exchanger and reheated to the operating temperature. Biogas contains toxic hydrogen sulfide, which damages the gas engines of a block thermal power plant [6], and carbon dioxide, which increases the heat of combustion. Therefore, after cooling, the gas enters the adsorber with artificially synthesized zeolites (permutites), which are now available for a good price and quality. The remaining biogas, mainly methane, is supplied to compressor units for compression and liquefaction [5]. Further, it is

directed to the compact block thermal power plants for generating electric and thermal energy in cogeneration plants. The gas tank is designed for averaging the consumption of biogas and is designed for a two-hour gas output. The gas flaring torch is used in emergency situations and when the plant is stopped for preventive maintenance.

Technological calculation. Three types of sludge are delivered to the sludge digester for decontamination: screenings, which are first crushed on crushers; sludge from primary settling tanks; waste activated sludge, which is pre-processed in silt compactors.

The amount of sludge dry matter (t/day) is calculated using the following expression [7]:

$$Q_{\text{сух}} = \frac{M(100-W)\rho}{100}, \tag{1}$$

where M — the amount of sludge, m^3/day.; W — moisture content of raw sludge, %; ρ — the density of sludge equal to 1 t/m^3 [7].

Screenings:

$$Q_{\text{сух}} = \frac{1.55(100-90)1}{100} = 0.155.$$

Sludge from the primary sedimentation tanks:

$$Q_{\text{сух}} = \frac{1423(100-96.5)1}{100} = 49.81.$$

Compacted waste activated sludge:

$$Q_{\text{сух}} = \frac{6378(100-99.25)1}{100} = 47.84.$$

1. The flow of sludge and silt on the ash-free basis (t/day) is determined by the formula [7]:

$$Q_{\text{без}} = \frac{Q_{\text{сух}}(100-B_{\text{г}})(100-S_{\text{ос}})}{100 \cdot 100}, \tag{2}$$

where $B_{\text{г}}$ — hygroscopic moisture content of sludge, 5%; $S_{\text{ос}}$ — ash content of dry matter for waste from screenings and sludge from primary sedimentation tanks 30 %, for activated sludge 25 % [7].

Screenings:

$$Q_{\text{без}} = \frac{0.155(100-5)(100-30)}{100 \cdot 100} = 0.1.$$

Sludge from the primary sedimentation tanks:

$$Q_{\text{без}} = \frac{49.81(100-5)(100-30)}{100 \cdot 100} = 33.12.$$

Compacted waste activated sludge:

$$Q_{\text{без}} = \frac{47.84(100-5)(100-25)}{100 \cdot 100} = 31.81.$$

Table 1

Sludge supply to the sludge digester

Sludge concentration	M, m^3/day	W, %	$Q_{\text{сух}}$, t/day	$Q_{\text{без}}$, t/day	Вг, %	$S_{\text{ос}}$, %
Screenings	1.55	90	0.155	0.1	5	30
From the primary sedimentation tanks	1423	96.5	49.81	33.12	5	30
Compacted waste activated sludge	6378	99.25	47.84	31.81	5	30
Total	$M_{\text{общ}}$=7802.55		$M_{\text{сух}}$=97.8	$M_{\text{без}}$=65.03		

2. The average moisture content of the mixture, %, is calculated by the formula [7]:

$$B_{\text{см}} = 100\left(1 - \frac{M_{\text{сух}}}{M_{\text{общ}}}\right), \tag{3}$$

$$B_{\text{см}} = 100\left(1 - \frac{97{,}8}{7802.55}\right) = 98.7.$$

3. The average ash content of the mixture,%, is expressed in [7]:

$$З_{см} = 100\left(1 - \frac{М_{без}}{Q_{сух}\left(\frac{100-В_г}{100}\right)+И_{сух}\left(\frac{100-В'_г}{100}\right)}\right), \tag{4}$$

where $О_{сух}$ total dry matter of the screenings and dry matter sludge from primary sedimentation tanks, t/day.; $И_{сух}$ — the amount of dry matter, compacted waste activated sludge, t/day.; $В_г$ — hygroscopic moisture content of the mixtures of screenings and dry matter sludge from primary clarifiers, %; $В'_г$ — hygroscopic moisture content of compacted waste activated sludge, % [7].

$$З_{см} = 100\left(1 - \frac{65.03}{49.965\left(\frac{100-5}{100}\right) + 47.835\left(\frac{100-5}{100}\right)}\right) = 30$$

4. The volume of the sludge digester, m^3, is determined by [7]:

$$V = M_{общ}\frac{100}{Д}, \tag{5}$$

where $М_{общ}$ — daily sludge consumption, m^3/day.; Д — daily amount of input of sludge in the digester, %. Depending on the mode of digestion of sludge and the moisture content of the sludge mixture that enters the digester, at sludge thermophilic mode and the humidity of 97% the sludge input Д=19 % [7].

$$V = 7802.55\frac{100}{19} = 41\,066.$$

We have three 9000 m^3 sludge digesters. The total volume of sludge digesters will be higher than the required one, and the actual input Д, %, will decrease [7]. Therefore

$$Д' = \frac{VД}{V_м n}, \tag{6}$$

where n — the number of sludge digesters, pcs.; $V_м$ — the volume of one sludge digester, m^3.

$$Д' = \frac{41066\cdot 19}{9000\cdot 3} = 29.$$

5. The mixture breakdown limit, %, is defined as [7]:

$$a_{см} = \frac{a_o Q_{без} + a_и U_{без}}{M_{без}}, \tag{7}$$

where $a_о$, $a_и$ — sludge breakdown limit 53 % and silt 44 %; $М_{без}$ — total volume of ash-free sludge and silt, t/day.; $Q_{без}$ — total volume of ash-free sludge, t/day; $U_{без}$ — volume of ash-free silt, t/day [7].

$$a_{см} = \frac{53\cdot 33.22+44\cdot 31.81}{65.03} = 48.6.$$

6. The gas emission per 1 kg of the loaded ash-free substance, m^3, is determined by [7]:

$$y' = \frac{a_{см} - nД'}{100}, \tag{8}$$

where n — the coefficient depending on the sludge humidity of 97% and the thermophilic fermentation mode, assumed to be 0.17.

$$y' = \frac{48{,}6 - 0.17\cdot 29}{100} = 0.44.$$

7. The total gas emission, m^3/day, so [7]:

$$Г = y'\cdot M_{без}\cdot 1000, \tag{9}$$

$$Г = 0.44\cdot 65.03\cdot 1000 = 28613.2.$$

8. Wet gas tanks are designed to smooth the gas pressure in the gas circuit, the capacity of which is Vг, m^3, we provide for 2-4 hours of gas output [7]:

$$V_г = \frac{3Г}{24}, \tag{10}$$

$$V_г = \frac{3\cdot 28613.2}{24} = 3576.65.$$

We suppose that one gas tank is 1820 m^3.

9. The amount of ash-free substance in the fermented mixture, t/day, is calculated by [7]:

$$М'_{без} = \frac{М_{без}(100-100y')}{100}, \tag{11}$$

$$\mathrm{M}'_{\text{без}} = \frac{65.03(100 - 100 \cdot 0.44)}{100} = 36.42.$$

10. The amount of dry matter in the digested mixture, t/day, is determined by [7]:

$$\mathrm{M}'_{\text{сух}} = \left(\mathrm{M}_{\text{сух}} - \mathrm{M}_{\text{без}}\right) + \mathrm{M}'_{\text{без}}, \quad (12)$$

where ($\mathrm{M}_{\text{сух}}$ — $\mathrm{M}_{\text{без}}$) — ash part, which is not subjected to transformation in the process of fermentation [7].

$$\mathrm{M}'_{\text{сух}} = (97.8 - 65.03) + 36.42 = 69.19.$$

11. The ash content of the fermented mixture,%, is determined by [7]:

$$\mathrm{З}'_{\text{см}} = 100 - \frac{\mathrm{M}'_{\text{без}} \cdot 100 \cdot 100}{\mathrm{M}'_{\text{сух}}(100 - \mathrm{B}''_{\text{г}})}, \quad (13)$$

where $\mathrm{B}''_{\text{г}}$ — the hygroscopic humidity of the fermented mixture, 6 % [7].

$$\mathrm{З}'_{\text{см}} = 100 - \frac{36.42 \cdot 100 \cdot 100}{69.19(100 - 6)} = 44.$$

12. The moisture content of the fermented mixture is calculated by [7]:

$$\mathrm{B}'_{\text{см}} = 100 - \frac{\mathrm{M}'_{\text{сух}}}{\mathrm{M}_{\text{общ}}} 100, \quad (14)$$

$$\mathrm{B}'_{\text{см}} = 100 - \frac{69.19}{7802.55} 100 = 99.1.$$

Conclusion. The paper considers one of the most serious environmental problems associated with the entry into the environment and long-term storage of sewage sludge. Active sludge is the greatest biological hazard, which occupies large areas near the urban area. For modernization, a technology for processing sewage sludge has been proposed, which also helps to solve two more problems. The resulting biogas can be used in the boiler shop of RAS, as well as cogeneration plants can use it to convert it into electrical energy and send it to treatment facilities. The fermented sludge after mechanical dewatering can be used as a fertilizer and, thanks to this, significantly reduce the area of silt detention ponds.

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Biotechnical toxicity assessment system of rare earth metals compounds

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Introduction. Expanding the scope of application of rare-earth metal compounds that are unique in their properties increases the interest of many researchers in studying the impact of rare-earth metals and their compounds on human health and the environment. One of the most relevant and modern methods for assessing the safety of the studied media for a biological test object is bioassay.

Problem Statement. The objective necessity of determining the combined effect of rare earth metals and their compounds on human health and the environment involves the use of biological systems. Modern methods of bioassay are extremely sensitive, which is sufficient to determine sub-threshold concentrations of hazardous substances in accordance with international standards. Thus, the use of these methods can make it possible to determine the index and the degree of toxicity of rare earth metal compounds with high accuracy in order to prepare a package of necessary documentation on industrial safety of products.

Theoretical Part. Based on the studied toxicological effects of rare earth metals, the authors proposed to conduct a toxicity assessment based on the concept of biotechnical systems. The object of research was oxides and carbonates of rare earth metals. The results of the study to determine the index and the degree of toxicity of rare earth metal compounds, as well as to assess the lethal concentration of LC50 (24 h) by biotesting using test organisms Paramecium Caudatum were used to write a safety data sheet for cerium oxide and carbonate.

Conclusion. The studies have shown that a certain modification of the technical solutions embedded in the devices of the Biotester series makes it possible to correctly solve the problem of assessing the toxicity of rare earth metals and their compounds. Based on the research results, the safety data sheets were developed.

Keywords: biotest analysis, infusorias, paramecium caudatum, rare-earth metals, oxides and carbonates, toxicity, toxicity index.

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Introduction. In the modern world, the scope of application of rare earth metals is increasing every year. Due to their unique physical and chemical properties, these materials have already found their application in such industries as metallurgy, oil production, textiles and agriculture. However, with the development of technologies, the range of applications of rare earth materials is constantly growing.

The discovery of unique catalytic, electrical, magnetic, and optical properties paved the way for the introduction of metals into more technologically complex processes for the production of mobile devices, hybrid cars, and wind turbines. In addition, the use of rare earth metals in clean energy technologies and safety systems has attracted global attention to these elements.

According to many studies on the effects of rare earth metals and their compounds on human health and the environment, it can be concluded that they are not safe.

One of the most relevant and modern methods for assessing the safety of the studied media for a biological test object is bioassay. Toxicity assessment is based on the concept of biotechnical systems (BTS). They are a combination of biological and technical elements combined into a single functional system of goal-oriented behavior.

Thus, the research to determine the index and degree of toxicity of rare earth metal compounds by bioassay to prepare a package of necessary documentation on industrial safety of products is very relevant.

Problem Statement. The subject of control and monitoring in the field of environmental protection, industry and pharmacology are often objects of not just variable, but fundamentally indeterminate composition, characterized by a large number of multicomponent ingredients that can also change their particular properties under the influence of external factors. The objective need to determine the cumulative effect of the entire complex of factors requires the use of new operational controls using biological systems that can simulate the effect of adverse factors on living organisms and, ultimately, on humans. Thus, the purpose of the research activity was to determine the index and degree of toxicity of rare earth metal compounds by bioassay to prepare a package of necessary documentation on industrial safety of products.

To achieve this goal, the following tasks are set:

- analysis of the possibility of using bioassay on protozoa to assess the toxicity of substances;
- determination of the toxicity index of the studied compounds;
- determination of the average lethal concentration of LC50 (24 h) using paramecium caudatum test organisms to determine the degree of toxicity of the studied substances;
- development of safety data sheets for cerium oxide and carbonate.

Theoretical Part. Properties of rare earth metals. Rare earth metals (REM) consist of seventeen elements, 15 of which are called lanthanides. Two additional elements, scandium (Sc) and yttrium (Y), are included in the list of rare earth metals because of their similar chemical and toxicological properties and because they are often found in the same ore deposits as other rare earth metals.

All metals in this group have very similar physical and chemical properties. Here are some of these properties:

- silvery-white soft metals that fade when they come into contact with air;
- solubility increases with increasing atomic number;
- high melting and boiling point;
- strong paramagnets;
- high electrical conductivity;
- active reducing agents;
- capable of exploding in the air;
- capable of fluorescence under ultraviolet light;
- dust of these compounds can be fire hazardous and explosive [1, 2].

Use of rare earth metals and their compounds. Rare earth metals play an increasingly important role in modern production. Their main application is in the production processes of "high technologies". Examples of such technologies include mobile phones, optical lenses, digital cameras, high-performance magnets, batteries, automotive catalytic converters, metal alloys, lasers, medical images, green energy devices, and aerospace weapons systems [1].

Some of the most commonly used forms of rare earth metals are carbonates and oxides. Oxides are mainly used to create laser installations, ceramic products and glass due to their unique optical properties. For example, lanthanum oxide is used to make special optical glasses, infrared adsorbing glass, and phosphors. Yttrium oxides are used in the production of ceramics and glass. They have high melting points and give the glass impact resistance and low expansion [2, 3].

Carbonates are mainly used for surface coatings or in the production of thermoelectric materials. For example, cerium carbonate covers the exhaust pipes of cars, since this compound absorbs exhaust gases [4].

Toxicological effect of rare earth metals and their compounds. Based on the atomic mass, REM is divided into two groups: "light" (Ce, Eu, Gd, La, Nd, Pr, and Sm) and "heavy" (Dy, Er, Ho, Lu, Tb, Tm, Y, and Yb). The role of REM in living systems is not fully understood. Light REM accumulates mainly in the liver, while heavy REM tends to replace calcium and accumulates in the bones. The toxicity of REM generally decreases with increasing atomic mass [1-3].

REM can affect the lungs, blood, destroy platelets, change the structure of DNA, and lead to disorders of the kidneys and brain. For example, gadolinium can accumulate in the soft tissues of the brain in the subarachnoid space of the brain. In addition, experiments were conducted that showed the effect of REM on fetal development in pregnant mice. However, none of the REM is currently classified as a carcinogen [1, 5].

Materials and methods for assessing the toxicity of REM compounds. The extensive use of REM in various production processes, as well as their ability to have a negative impact on the environment and the human body, lead to the need to assess the degree of harmful effects of metal and draw up the necessary documentation on product safety.

A measuring bioassay system is a set of methodological and hardware tools aimed at assessing the toxicity of substances based on the biological activity of test objects.

Bioassay is a procedure for detecting environmental toxicity using test objects that signal danger, regardless of what substances and in what combinations changes in the vital functions of the test objects were caused [6].

The construction of the bioassay system is based on the general principles of creating biotechnical systems (Fig. 1).

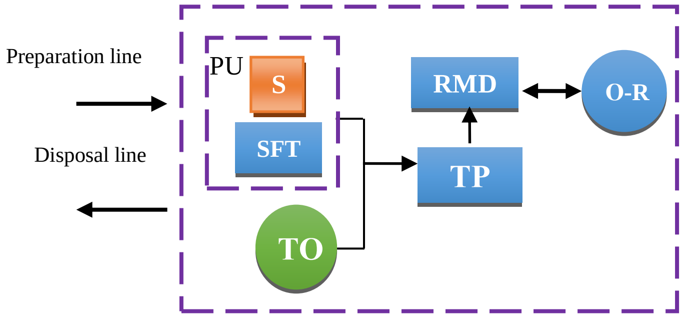

Fig. 1. Bioassay biotechnical system:
S — sample; TO — bioobject used as a test object;
PU — sample preparation unit; SFT — sample forming tools;
RMD — reaction monitoring devices; O–R — operator-researcher;
* special disposal is not required due to non-pathogenicity of the culture

The main function of the bioassay channel is to obtain a numerical indicator with certain accuracy at the output. From the point of view of biotechnical systems, bioassay is a measurement task that has some measured parameters and its own metrological support. The principle of operation of the bioassay system can be represented as a mathematical model in which the function of distribution of the concentration of a toxic substance in space and time will be implemented by the function of distribution of toxicity. At the same time, an important part in the development of bioassay systems is the creation of a measuring converter. Optical measurement converters are most often used, since they have a minimum error. The optical-acoustic method can also be used to directly measure the optical characteristics of scattering media. Among other things, the bioassay system must also include the environment of the laboratory where the testing is performed, since it is the environment that must meet certain conditions for temperature and humidity, and must not contain toxic substances.

Another part of the bioassay system is the test object (TO).

When conducting a bioassay analysis, various organisms can serve as a test object: infusoria, daphnia, algae, fish, etc. The choice of the test object depends on the test reaction that is planned to be recorded and the environment that is being biotested.

One of the most common and convenient test objects for bioassay is the Paramecium Caudatum infusoria. Infusoria has a number of properties, due to which its use is most appropriate:

— biological significance: infusoria P. Caudatum is one of the most common types of laboratory organisms;

— harmlessness to humans and animals;

— good knowledge;

— high sensitivity to toxic substances;

— availability of cultivation for any practical laboratory;

— low cost of culture;

— pronounced taxis [6].

This organism belongs to the protozoa subkingdom, the Ciliphora type. In the natural environment, Paramecium caudatum is common in fresh water bodies, such as lakes, swamps, ponds, etc. The shape of the cell is ellipsoid, the dimensions are 200 × 40 microns. The main food of the infusoria is bacteria, yeast, etc. Reproduction of the infusoria occurs by transverse cell division. The surface of the body of infusoria is covered with cilia, which serve both to move in the aquatic environment and serve as receptors that perceive chemical stimuli.

A distinctive feature of the infusoria is its continuous movement. Moreover, the nature of this movement may change depending on the surrounding factors. A special feature of infusoria is the presence of negative geotaxis — the property of infusoria to float into the upper layers of the liquid, which is characterized as movement against the Earth's gravitational field. But what is most important is the reaction of protozoa to toxic substances. The constant desire of infusoria to find their comfort zone leads to motor responses to chemical stimuli. If toxic substances are harmful to protozoa, infusoria will try to swim away from them. This phenomenon is called chemotaxis.

It is worth noting that the chemotactic reaction of infusoria is stronger than the geotactic one [7]. The chemotactic reaction is realized if there is a stable gradient of chemical concentrations over time.

When bioassay is conducted on infusoria, the toxicity of the test sample is judged by the survival rate, the intensity of reproduction, changes in motor activity, behavioral (taxic) reactions, etc. [8].

In this study, the assessment was based on the index and degree of toxicity of rare earth metal compounds based on the chemotactic reaction.

The lethal concentration of LC50 was also determined. The duration of the experiment in this case was 24 hours.

As a safety assessment of the product (sample), the following rare earth metals were studied: neodymium, yttrium, cerium, lanthanum, praseodymium and gadolinium.

To obtain objective quantitative information about the test reaction, a reaction monitoring device (RMD) was used, which is a Boitester-2M device.

Application of the "Biotester" series device for assessing the toxicity of rare earth metals. The study was conducted in accordance with PND F T 16.3.1-10 "Methodology for determining the toxicity of production and consumption waste by express method using a device of the "BIOTESTER" series, since the compounds under study are inorganic powdery chemicals [9].

Taking into account the fact that the chemotactic reaction is realized under the condition that there is a stable gradient of chemical concentrations in time, in this method, such a gradient is created by superimposing two media on

each other: a suspension containing infusoria and the test sample. The two media are arranged vertically relative to each other: the upper one will be a sample, and the lower one will be a suspension of infusoria. To ensure that the media do not mix with each other, it is necessary to achieve a difference in the densities of the two media, while leaving the possibility of free movement of infusoria between them.

The criterion of toxic effect is a significant difference in the number of infusoria cells between the two zones. If the test sample does not contain toxic substances, the concentration of infusoria cells in the upper zone will be observed in the cuvette. And the higher the toxicity of the sample, the less infusoria will be distributed in it.

Biotester-2M is a device that determines the concentration of particles in a homogeneous medium by the amount of the transmitted radiation. The main principle of the device is to read changes in the flow of the transmitted radiation. To realize this phenomenon, a light source or emitter and a photodetector must be present.

A cuvette containing a gradient medium, i.e., the overlay of the toxic sample under study on the solution with infusoria, is placed between the light source (LS) and the receiver (R). The emitter emits a light flux of a certain area S. Each object interacts with the radiation at the intersection of the flow, like a transparent sphere obeying the laws of geometric optics (Fig. 2) [10].

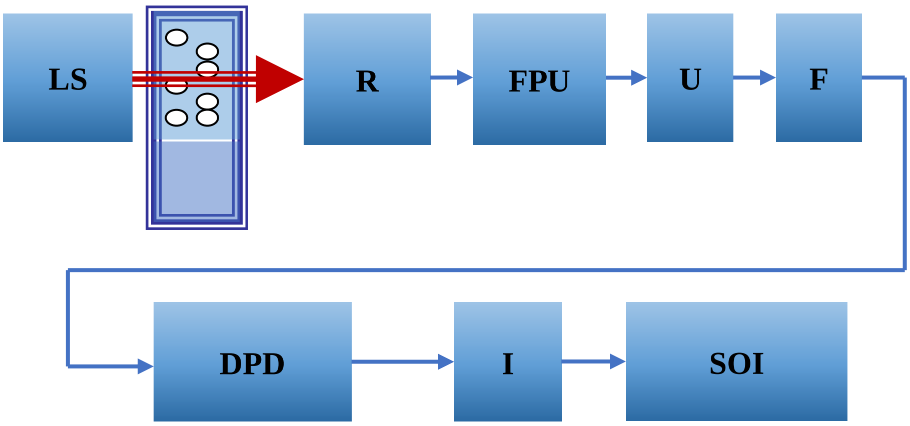

Fig. 2. Block diagram of the Biotester-2M device

In other words, each infusoria that falls under the light beam will change its intensity. The change in intensity will be detected by the photodetector that receives the light beam. In this case, the quantitative change in light intensity is proportional to the number of infusoria.

Each of the studied samples was analyzed in 3 cuvettes, 5 readings of the BIOTESTER-2M device were taken from each cuvette.

According to PND F T 16.3.16-10, to prevent gross errors during the analysis, the acceptability of the control sample was promptly evaluated according to the following inequality:

$$|Ikmax - Ikmin| \leq 0{,}2Icp.k, \tag{1}$$

where $Ikmax$ — the maximum readings of the device for control samples, $Ikmin$ — the minimum readings of the device for control samples, $Icp.k$ — the average readings of the device for control samples [9].

The toxicity of the sample was assessed by the relative difference in the number of infusoria in the upper zone of the cuvette in the control and the analyzed samples. In accordance with PND F T 16.3.16-10, the toxicity index is calculated by the formula:

$$T = \frac{|I\text{ср.к} - I\text{ср.пр}|}{I\text{ср.к}} \times K, \quad (2)$$

where $I_{ср.k}$ — the average instrument reading for control samples, $I_{ср.пр}$ — the average instrument reading for analyzed samples, К — the sample dilution coefficient. The toxicity index T is a dimensionless value and can take values from 0 to 1 in accordance with the degree of toxicity of the analyzed sample.

According to PND F T 16.3.16-10, depending on the index value, the samples are classified according to their degree of toxicity into 3 groups:

— I. Acceptable degree of toxicity ($0.00 < T \leq 0.40$).

— II. Moderate degree of toxicity ($0.40 < T \leq 0.70$).

— III. High degree of toxicity ($T > 0.70$).

Determination of the average lethal concentration of LC50 (24 h) using test organisms Paramecium caudatum. The method consists in recording the survival rate of freshwater test organisms Paramecium caudatum in the analyzed sample of the object under study relative to the control sample, determining its toxicity and toxicological parameters during 6, 24 or 96 hours of testing [11].

Determination of toxicity and average lethal concentration of LC50 (24 h) was carried out in accordance with GOST R 57166-2016 "Water. Determination of toxicity by survival of freshwater infusoria Paramecium caudatum".

To prepare the analytical solution, it is necessary to use 50 grams of a dry rare earth metal compound and 450 ml of distilled water. Then, for 6-7 hours, mixing takes place using a magnetic stirrer at a minimum speed. After the end of mixing, the mixture settles for 14 hours. The supernatant is passed through the filter paper. After 24 hours, the containers with the analyzed solution are visually examined and the number of surviving infusoria is calculated [11].

Research Result. The toxicity indices (excluding the dilution coefficient) obtained by ten-fold dilution of carbonates of the studied substances are shown in fig. 3 (the red line on the diagram indicates the level of non-toxicity of the sample).

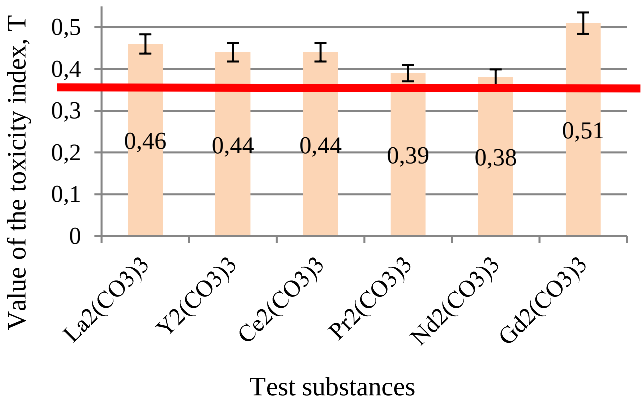

Fig. 3. Value of toxicity indices of carbonates of the studied metals at 10-fold dilution of the sample

As it can be seen from the diagram, when diluted tenfold, praseodymium and neodymium carbonate are considered non-toxic in accordance with PND F T 16.3.16–10 ($T \leq 0.40$). And the remaining samples of carbonates of the studied rare earth metals must be diluted 100 times. The values of the toxicity indices of a hundredfold dilution (excluding the dilution coefficient) are shown in fig. 4.

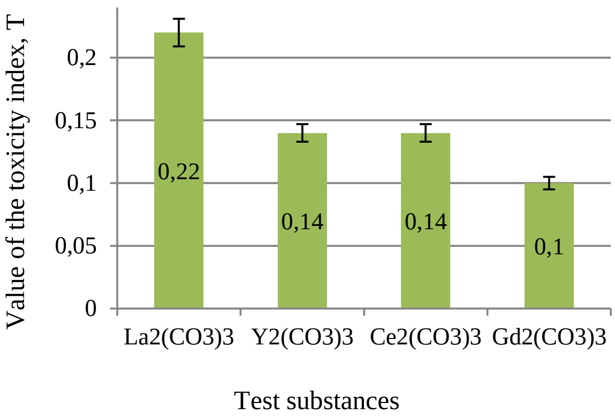

Fig. 4. Value of the toxicity indices of carbonates of the studied metals at 100-fold dilution of the sample

The resulting diagram shows that at 100-fold dilution, the carbonates of the studied rare earth metals are non-toxic in accordance with PND F T 16.3.16–10 ($T \leq 0.40$).

The final values of the toxicity indices of carbonates of the studied rare earth metals are presented in table 1.

Table 1

Toxicity indices of the studied rare earth metal carbonates

Determined indicator	Analysis result		Toxicity index (excluding degree of dilution)	Degree of toxicity of the sample, T
	Test substance	Dilution degree		
Toxicity of the sample on Paramecium caudatum infusoria	$La_2(CO_3)_3$	100	0.22	High, T = 22
	$Y_2(CO_3)_3$	100	0.14	High, T = 14
	$Ce_2(CO_3)_3$	100	0.14	High, T = 14
	$Pr_2(CO_3)_3$	10	0.39	High, T = 3.9
	$Nd_2(CO_3)_3$	10	0.38	High, T = 3.8
	$Gd_2(CO_3)_3$	100	0.1	High, T = 10

In addition to carbonates, the toxicity indices were calculated for oxides of the studied compounds. The toxicity indices (excluding coefficient 0.22; 0.14; 0.14; 0.1; 0; 0.05; 0.1; 0.15; 0.2; La2(CO3) 3 Y2(CO3) 3 Ce2(CO3)3 Gd2(CO3) 3. The values of the toxicity indeces obtained by tenfold dilution of the oxides of the studied metals are shown in fig. 5 (the red line on the diagram indicates the level of non-toxicity of the sample).

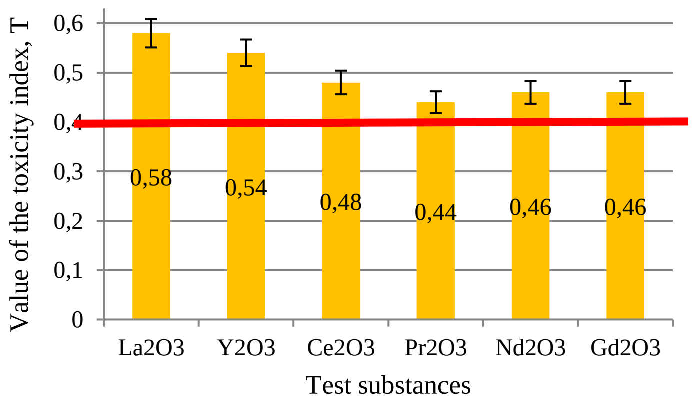

Fig. 5. Value of toxicity indices of oxides of the studied metals at 10-fold dilution of the sample

As it can be seen from the diagram, with a tenfold dilution, all the oxides under consideration are toxic compounds in accordance with PND F T 16.3.16-10 (T ≤ 0.40); therefore, it is necessary to dilute the samples of the studied substances 100 times. The values of the toxicity indices of a hundredfold dilution (excluding the dilution coefficient) are shown in fig. 6.

The resulting diagram shows that at 100-fold dilution, the oxides of the studied rare earth metals are non-toxic in accordance with PND F T 16.3.16-10 (T ≤ 0.40).

The final values of the toxicity indices of the oxides of the rare earth metals under consideration are presented in table 2.

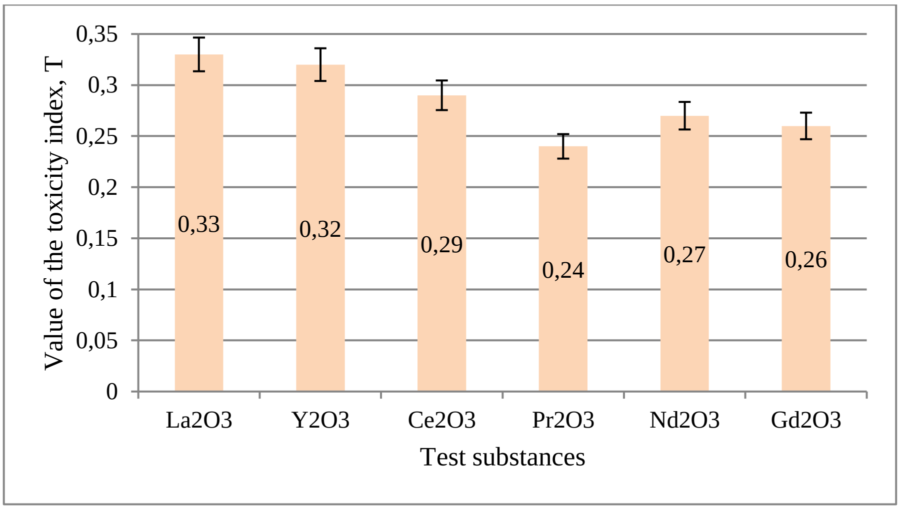

Fig. 6. Value of toxicity indices of oxides of the studied metals at 100-fold dilution of the sample

Table 2

Toxicity indices of the studied rare earth metal oxides

Determined indicator	Analysis result		Toxicity index (excluding degree of dilution)	Degree of toxicity of the sample, T
	Test substance	Dilution degree		
Toxicity of the sample on Paramecium caudatum infusoria	La_2O_3	100	0.33	High, T = 33
	Y_2O_3	100	0.32	High, T = 32
	Ce_2O_3	100	0.29	High, T = 29
	Pr_2O_3	100	0.24	High, T = 24
	Nd_2O_3	100	0.27	High, T = 27
	Gd_2O_3	100	0.26	High, T = 26

The measurement results of the toxicity indeces of carbonates and oxides of rare earth metals were evaluated for acceptability in accordance with the recommendations presented in PND F T 16.3.16–10. The convergence of the results of parallel definitions was checked by the formula:

$$|T - Tmax, \min| \leq r, \quad (3)$$

where r — the ratio of operational control of convergence (r = 0.43T); T — the arithmetic average of the results of 3 parallel measurements of toxicity index in arbitrary units; T_{max} — the maximum value of the toxicity index of the sample of three parallel measurements; T_{min} — the minimum value of the toxicity index of the sample of three parallel measurements.

According to the evaluation, the condition (3) is met for each of the results, which means that the results obtained can be considered reliable.

Determination of toxicity and average lethal concentration of LC50 (24 h) was carried out in accordance with GOST R 57166-2016 "Water. Determination of toxicity by survival of freshwater infusoria Paramecium caudatum".

The results of the analysis are presented in table 3.

Table 3

Results of bioassay for acute toxicity

Substance	Testing duration, h	Mass concentration of the substance, mg/dm^3	Number of surviving organisms in containers, PCs			Arithmetic mean of the number of surviving organisms, PCs.	Percentage of death of text-organisms, %
			1	*2*	*3*		
La_2O_3	24	0(control)	30	30	30	30	0
		0.00424	17	16	16	16	46
		0.02924	16	17	14	16	48
		0.05424	15	13	17	15	50
		0.07924	12	13	12	12	59
		0.10424	11	12	13	12	60
Y_2O_3	24	0(control)	30	30	30	30	0
		0.0064	16	18	18	17	42
		0.0314	15	16	18	16	46
		0.0564	14	14	17	15	50
		0.0814	12	11	14	12	59
		0.1064	12	11	13	12	60
Ce_2O_3	24	0(control)	30	30	30	30	0
		0.062	18	17	16	17	43
		0.087	14	17	14	15	50
		0.112	14	11	13	13	58
		0.137	13	11	12	12	60
		0.162	10	9	11	10	67
Pr2O3	24	0(control)	30	30	30	30	0
		0.047	26	27	26	26	12
		0.072	23	23	24	23	22
		0.097	16	12	17	15	50
		0.122	13	11	14	13	58
		0.147	11	10	12	11	63
Nd2O3	24	0(control)	30	30	30	30	0
		0.06	19	20	21	20	33
		0.085	18	18	17	18	41
		0.11	17	16	18	17	43
		0.135	15	13	17	15	50
		0.16	11	13	16	13	56

Gd_2O_3	24	0(control)	30	30	30	30	0
		0.4	14	16	17	16	48
		0.425	13	17	15	15	50
		0.45	11	12	10	11	63
		0.475	10	11	8	10	68
		0.5	9	8	9	9	71
$La_2(CO_3)_3$	24	0(control)	30	30	30	30	0
		0.009	19	19	20	19	36
		0.034	18	17	19	18	40
		0.059	16	18	15	16	46
		0.084	15	17	13	15	50
		0.109	13	15	11	13	57
$Y_2(CO_3)_3$	24	0(control)	30	30	30	30	0
		0.0155	18	19	20	19	37
		0.0405	17	16	17	17	44
		0.0655	15	15	18	16	47
		0.0905	13	13	18	15	50
		0.1155	12	11	14	12	59
$Ce_2(CO_3)_3$	24	0(control)	30	30	30	30	0
		0.101	17	20	18	18	39
		0.126	17	18	15	17	44
		0.151	15	18	12	15	50
		0.176	14	13	12	13	57
		0.201	12	13	11	12	60
$Pr_2(CO_3)_3$	24	0(control)	30	30	30	30	0
		0.078	17	20	19	19	38
		0.103	16	18	17	17	43
		0.128	14	17	16	16	48
		0.153	14	16	15	15	50
		0.178	11	12	14	12	59
$Nd_2(CO_3)_3$	24	0(control)	30	30	30	30	0
		0.16	18	20	18	19	38
		0.185	16	18	16	17	44
		0.21	14	15	15	15	50
		0.235	13	14	14	14	54
		0.26	12	13	13	13	58
$Gd_2(CO_3)_3$	24	0(control)	30	30	30	30	0
		0.59	18	16	20	18	40
		0.615	16	15	18	16	46
		0.64	16	13	17	15	50

		0.665	14	12	15	14	54
		0.69	11	10	15	12	60

According to the results of bioassay performed in accordance with GOST R 57166-2016, it is clear that the samples are highly toxic and pose a danger to the environment and humans.

Conclusion. Based on the results of the research, the toxicity indices of compounds of a number of rare earth metals were determined. According to PND F T 16.3.16-10 "Methodology for determining the toxicity of production and consumption waste by express method using a device of the "BIOTESTER" series", these substances are highly toxic compounds. Based on the results of the analysis of the average lethal concentration of LC50 (24 h) using Paramecium caudatum test organisms, it was proved that these compounds are highly toxic in accordance with GOST R 57166-2016.

Based on the research results, safety data sheets were developed in accordance with GOST 30 333-2007 "Safety data sheet for chemical products. General requirements" and R 50.1.102-2014 "Preparation and registration of a safety data sheet for chemical products". The results obtained are included in section 12 "Information on environmental impact".

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Measures to optimize traffic and the environment. Calculations of environmental safety on a given section of the Rostov-on-Don road network

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Introduction. One of the most pressing socio-economic problems is the state of the environment, which affects the living conditions of many people. The article deals with the problem areas of the intersection of 20-ya Liniya street – Sholokhov Avenue in Rostov-on-Don.

Problem Statement. The purpose of this paper is to improve environmental safety at the intersection of 20-ya Liniya street – Sholokhov Avenue in Rostov-on-Don by reducing emissions from road transport through the proposed measures to reorganize traffic on this section of the road network.

Theoretical Part. The article provides an assessment of environmental and road safety on the road network section before applying the proposed measures. The measures are listed and justified that would help improve the conditions for road transport at the selected intersection and reduce emissions from road transport, which would improve environmental safety. The calculation of environmental indicators was made after the proposed measures to reduce NOx emissions by cars.

Conclusion. The article analyzes the environmental indicators before and after the events, and then compares them. Based on the analysis and calculations, it is determined how much the proposed measures to optimize traffic will help reduce NOx emissions by cars.

Keywords: environment, measures to optimize traffic, environmental safety, mass consumption of NOx, ecology, section of the road network, engine, traffic flow.

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Introduction. One of the most pressing socio-economic problems is the state of the environment, which affects the living conditions of many people. The growth of technological progress is associated with an increase in the number of vehicles on the roads. Cars, in turn, are one of the main mass pollutants of the atmosphere. They pose a threat to human health associated with emissions and waste, as well as the impact of noise from traffic flows [1].

In recent years, Russia has been experiencing serious environmental pollution, which is a critical threat to public health and sustainable development. Energy activities are the dominant source of air pollution. The amount of carbon dioxide (CO_2) emitted by power plants into the atmosphere is approximately 40% of the total CO_2 emissions. The same indicator for power plant pollutants is 30 %. In addition, it has been found that vehicles are making an increasing contribution to air pollution due to the rapid growth of traffic. Transport accounts for 20-67 % of carbon monoxide (CO) emissions, 12-36% of NO_x oxynitride emissions, and 12-39% of hydrocarbon compound (HC) emissions. The scale of emissions in most regions of Russia exceeds the possibilities of self-purification and diffusion of pollutants from the atmosphere. At present, there is an acute conflict between the growing demand for energy, the excessive number of vehicles and the "high coal content" in the energy balance, on the one hand, and the imperative to mitigate air pollution, on the other [2, 3].

Problem Statement. The aim of the work is to improve the environmental situation at the intersection of 20-ya Liniya street and Sholokhov Avenue in Rostov-on-Don by reducing emissions from road transport through measures to reorganize traffic on this section of the road network. It is also necessary to assess the environmental safety and road safety on the section of the road network (RN) before applying the proposed measures.

After studying the situation at the above-mentioned intersection, it can be concluded that there is a possibility of improving the conditions for road transport at this interchange. The problem factors in the surveyed area are:

— irrationally selected cycle of operation of two traffic lights;

— no traffic lay-by for municipal transport.

It is assumed that the key problem of this intersection is the wrong cycle of traffic lights. This problem is particularly felt in peak hours when the traffic intensity increases significantly. It is recorded that the duration of the permissive signal for pedestrians crossing Sholokhov Avenue is only 24 seconds. The width of the road on this section is 13 meters. For an ordinary person, this time is more than enough. However, for people with limited mobility, given the absence of various types of descents from curbs or ramps, the situation becomes critical [4].

Buses and minibuses moving from the suburban bus station towards Karl Marx square can turn left on 20-ya Liniya street during the operation of the traffic light permissive signal. However, during peak hours, the number of moving vehicles on routes increases, which means that the traffic intensity of municipal transport increases. Buses and minibuses gather at this intersection, and 20 seconds is clearly not enough for them. Everything could be corrected by adding only 10 seconds to the time of the traffic light's permissive signal.

Also, an important condition for increasing the passability of this section is the organization of a traffic lay-by at the bus stop, before reaching the 9th Dormitory of the Don State Technical University. By extending the stop by three meters towards the sidewalk, it would be possible to get a wide traffic lay-by, which would allow buses not to block the flow moving towards the ring at the suburban bus station. The implementation of a traffic lay-by at the stop would increase the passability of this section without violating the relevant standards [4, 5].

Theoretical Part. According to the environmental monitoring data, on the section of the road transport network along Sholokhov Avenue near 20-ya Liniya there is an increased content of nitrogen oxides NO_x. According to preliminary calculations, NOx emission is 11.2 g/s. As a result of the environmental actions, the speed of traffic increased from 6.8 m/s to 8.2 m/s. Let us calculate the mass of NOx emissions from the transport stream afterwards. The length of a section of the street road network is L = 111.6 m, and the number of lanes in each direction is z = 3 [6].

The speed of passenger cars v is determined by the formula (1):

$$v = 1.8665 v_{m.n.}, \tag{1}$$

where $v_{m.n.}$ — the speed of the traffic flow

Using formula (1), we determine the speeds of groups of cars.

Speed of passenger vehicles (PV):

$$v_{j1} = 1.8665 \cdot 8.2 \approx 15.31 \text{ m/s.}$$

Minibus speed:

$$v_{j2} = 0.575 \cdot 15.31 \approx 8.8 \text{ m/s.}$$

Speed of cargo vehicles and buses:

$$v_{j3} = v_{j4} = 0.4465 \cdot 15.3 \approx 6.84 \text{ m/s.}$$

The product $\delta_{вр} a$ for passenger vehicles can be represented by the expression:

$$\pm\delta_{вр} a = g(2,023 v^{-1,0678} - \psi), \tag{2}$$

where $\delta_{вр}$ — the coefficient accounting for rotating mass; a — vehicle acceleration, m/s^2; g — gravity acceleration, m/s^2; ψ — the coefficient of reduced road resistance, it can be calculated by the formula:

$$\psi = (f \pm tg\gamma)\cos\gamma ,$$

whre f — coefficient of rolling resistance, taken as f = 0,02; γ — the angle between the surface of the roadway and the horizontal plane.

Let us determine the product for passenger vehicles groups using the formula.

Passenger vehicles:

$$\delta_{вр} a = 9{,}87[2{,}023 \cdot 15{,}31^{-1{,}0678} - (0{,}02 - tg4)] = -6{,}257 \text{ m/s}^2.$$

Minibuses:

$$\delta_{вр} a = 9{,}87[1{,}6851 \cdot 8{,}8^{-1{,}3825} - (0{,}02 - tg4)] = -6{,}518 \text{ m/s}^2.$$

Cargo vehicles and buses:

$$\delta_{вр} a = 9{,}87[0{,}5502 \cdot 6{,}84^{-1{,}11} - (0{,}02 - tg4)] = -6{,}698 \text{ m/s}^2.$$

The equation for determining the relative power of car engines, depending on their purpose and the type of fuel used, has the form [7, 8]:

$$\overline{N} N_{ном} = \frac{[k_ф \rho_в F_s v_j^2 + mg\cos\gamma(f \pm tg\gamma) \pm \delta_{вр} am] v_j}{\eta_{тр}}, \tag{3}$$

where $\overline{N} N_{ном}$ — the product, representing the effective power of the engine, W, where $N_{ном}$ — rated engine power, W; $k_ф$ — coefficient of streamlining; $\rho_в$ — air density, $\rho_в$=1.293 kg/n^3; F_s — frontal area of the vehicle, m^2; m — mass of the vehicle, kg $\eta_{тр}$ — transmission efficiency.

The minus signs in equation (3) are placed before the complexes of values $tg\gamma$ and $\delta_{вр}am$, respectively, when moving downhill and when the acceleration of translational motion is negative (movement with deceleration). Let us substitute the values of the mass, power, and aerodynamic characteristics of the passenger vehicle in equation (3) and get the values of the relative power of car engines.

Relative power of passenger cars with carburetor-type petrol engines:

$$\overline{N} = \frac{\left[0{,}15 \cdot 1{,}293 \cdot 1{,}5 \cdot 15{,}31^2 + 1750 \cdot 9{,}87 \cdot \cos 4 \cdot \left(0{,}02 - tg4\right) - 6{,}257 \cdot 1750\right] \cdot 15{,}31}{60000 \cdot \left(-2{,}9224\overline{N}^3 + 3{,}4211\overline{N}^2 - 1{,}0995\overline{N} + 1{,}0299\right)}.$$

It follows:

$$-2{,}9224\overline{N}^4 + 3{,}4211\overline{N}^3 - 1{,}0995\overline{N}^2 + 1{,}0299\overline{N} - 0{,}5013 = 0 .$$

$\overline{N}_1 = 0{,}969$ and $\overline{N}_2 = 0{,}516$. Let us take $\overline{N} = \overline{N}_2 = 0{,}516$. This equation has 2 real roots $\overline{N}_1 = 0{,}959$ and $\overline{N}_2 = 0{,}536$, one of which ($\overline{N}_1$)is approximately equal to one. Based on the physical meaning, we can assume that at these speeds it is impossible to get such a relative power of the first root as a result. Therefore, the most likely option is a real root ($\overline{N}_2$). Thus $\overline{N} = \overline{N}_2 = 0{,}536$.

Relative power of passenger cars with injection-type petrol engines:

$$\overline{N} = \frac{\left[0{,}15 \cdot 1{,}293 \cdot 1{,}5 \cdot 15{,}31^2 + 1750 \cdot 9{,}87 \cdot \cos 4 \cdot \left(0{,}02 - tg4\right) - 6{,}257 \cdot 1500\right] \cdot 15{,}31}{60000 \cdot \left(-3{,}2715\overline{N}^3 + 3{,}8372\overline{N}^2 - 1{,}2194\overline{N} + 1{,}0006\right)}.$$

It follows:

$$-3{,}2715\overline{N}^4 + 3{,}8372\overline{N}^3 - 1{,}2194\overline{N}^2 + 1{,}0006\overline{N} - 0{,}5013 = 0 .$$

$\overline{N}_1 = 0{,}937$ and $\overline{N}_2 = 0{,}53$, let us take $\overline{N} = \overline{N}_2 = 0{,}53$.

Relative power of passenger cars with diesel engines:

$$\overline{N} = \frac{\left[0{,}15 \cdot 1{,}293 \cdot 1{,}5 \cdot 15{,}31^2 + 1750 \cdot 9{,}87 \cdot \cos 4 \cdot \left(0{,}02 - tg4\right) - 6{,}257 \cdot 1750\right] \cdot 15{,}31}{70000 \cdot \left(-1{,}3238\overline{N}^3 + 1{,}118\overline{N}^2 - 0{,}031\overline{N} + 0{,}8755\right)}.$$

It follows:

$$-1{,}3238\overline{N}^4 + 1{,}118\overline{N}^3 - 0{,}031\overline{N}^2 + 0{,}8755\overline{N} - 0{,}4297 = 0 .$$

$\overline{N}_1 = 1{,}12$ and $\overline{N}_2 = 0{,}445$, let us take $\overline{N} = \overline{N}_2 = 0{,}445$.

Relative power of passenger cars with gas engines:

$$\overline{N}=\frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 15,31^2+1750\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,257\cdot 1750\right]\cdot 15,31}{55000\cdot \left(-2,9224\overline{N}^3+3,4211\overline{N}^2-1,0995\overline{N}+1,0299\right)}.$$

It follows:

$$-2,9224\overline{N}^4+3,4211\overline{N}^3-1,0995\overline{N}^2+1,0299\overline{N}-0,5468=0.$$

$\overline{N}_1=0,946$ and $\overline{N}_2=0,562$, let us take $\overline{N}=\overline{N}_2=0,562$.

Relative power of minibuses with carburetor-type petrol engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3\cdot 8,8^2+2750\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,518\cdot 2750\right]\cdot 8,8}{90000\cdot \left(-2,9224\overline{N}^3+3,4211\overline{N}^2-1,0995\overline{N}+1,0299\right)}.$$

It follows:

$$-2,9224\overline{N}^4+3,4211\overline{N}^3-1,0995\overline{N}^2+1,0299\overline{N}-0,2344=0.$$

$\overline{N}_1=1,06$ and $\overline{N}_2=0,254$, let us take $\overline{N}=\overline{N}_2=0,254$.

Relative power of minibuses with injection-type petrol engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3\cdot 8,8^2+2750\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,518\cdot 2750\right]\cdot 8,8}{90000\cdot \left(-3,2715\overline{N}^3+3,8372\overline{N}^2-1,2194\overline{N}+1,0006\right)}.$$

It follows:

$$-3,2715\overline{N}^4+3,8372\overline{N}^3-1,2194\overline{N}^2+1,0006\overline{N}-0,2344=0.$$

$\overline{N}_1=1,03$ and $\overline{N}_2=0,265$, let us take $\overline{N}=\overline{N}_2=0,265$.

Relative power of minibuses with diesel engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3\cdot 8,8^2+2750\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,518\cdot 2750\right]\cdot 8,8}{90000\cdot \left(-1,3238\overline{N}^3+1,118\overline{N}^2-0,031\overline{N}+0,8755\right)}.$$

It follows:

$$-1,3238\overline{N}^4+1,118\overline{N}^3-0,031\overline{N}^2+0,8755\overline{N}-0,2344=0.$$

$\overline{N}_1=1,18$ and $\overline{N}_2=0,263$, let us take $\overline{N}=\overline{N}_2=0,263$.

Relative power of minibuses with gas engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3\cdot 8,8^2+2750\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,518\cdot 2750\right]\cdot 8,8}{65000\cdot \left(-2,9224\overline{N}^3+3,4211\overline{N}^2-1,0995\overline{N}+1,0299\right)}$$

It follows:

$$-2,9224\overline{N}^4+3,4211\overline{N}^3-1,0995\overline{N}^2+1,0299\overline{N}-0,3246=0.$$

$\overline{N}_1=1,036$ and $\overline{N}_2=0,346$, let us take $\overline{N}=\overline{N}_2=0,346$.

Relative power of cargo vehicles with carburetor-type petrol engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3,5\cdot 6,84^2+4000\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 4000\right]\cdot 6,84}{72000\cdot \left(-2,9224\overline{N}^3+3,4211\overline{N}^2-1,0995\overline{N}+1,0299\right)}.$$

It follows:

$$-2,9224\overline{N}^4+3,4211\overline{N}^3-1,0995\overline{N}^2+1,0299\overline{N}-0,2532=0.$$

$\overline{N}_1=1,06$ and $\overline{N}_2=0,274$, let us take $\overline{N}=\overline{N}_2=0,274$.

Relative power of cargo vehicles with injection-type petrol engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3,5\cdot 6,84^{2}+4000\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 4000\right]\cdot 6,84}{72000\cdot \left(-3,2715\overline{N}^{3}+3,8372\overline{N}^{2}-1,2194\overline{N}+1,0006\right)}$$

It follows:

$$-3,2715\overline{N}^{4}+3,8372\overline{N}^{3}-1,2194\overline{N}^{2}+1,0006\overline{N}-0,2532=0.$$

$\overline{N}_1=1,03$ and $\overline{N}_2=0,285$, let us take $\overline{N}=\overline{N}_2=0,285$.

Relative power of cargo vehicles with diesel engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3,5\cdot 6,84^{2}+10250\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 10250\right]\cdot 6,84}{125000\cdot \left(-1,3238\overline{N}^{3}+1,118\overline{N}^{2}-0,031\overline{N}+0,8755\right)}.$$

It follows:

$$-1,3238\overline{N}^{4}+1,118\overline{N}^{3}-0,031\overline{N}^{2}+0,8755\overline{N}-0,3656=0.$$

$\overline{N}_1=1,13$ and $\overline{N}_2=0,395$, let us take $\overline{N}=\overline{N}_2=0,395$.

Relative power of cargo vehicles with gas engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 3,5\cdot 6,84^{2}+10250\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 10250\right]\cdot 6,84}{80000\cdot \left(-1,3238\overline{N}^{3}+1,118\overline{N}^{2}-0,031\overline{N}+0,8755\right)}.$$

It follows:

$$-1,3238\overline{N}^{4}+1,118\overline{N}^{3}-0,031\overline{N}^{2}+0,8755\overline{N}-0,5713=0.$$

$\overline{N}_1=1,03$ and $\overline{N}_2=0,606$, let us take $\overline{N}=\overline{N}_2=0,606$.

Relative power of buses with carburetor-type petrol engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 7,5\cdot 6,84^{2}+5000\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 5000\right]\cdot 6,84}{100000\cdot \left(-2,9224\overline{N}^{3}+3,4211\overline{N}^{2}-1,0995\overline{N}+1,0299\right)}.$$

It follows:

$$-2,9224\overline{N}^{4}+3,4211\overline{N}^{3}-1,0995\overline{N}^{2}+1,0299\overline{N}-0,2337=0.$$

$\overline{N}_1=1,06$ and $\overline{N}_2=0,253$, let us take $\overline{N}=\overline{N}_2=0,253$.

Relative power of buses with injection-type petrol engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 7,5\cdot 6,84^{2}+5000\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 5000\right]\cdot 6,84}{100000\cdot \left(-3,2715\overline{N}^{3}+3,8372\overline{N}^{2}-1,2194\overline{N}+1,0006\right)}.$$

It follows:

$$-3,2715\overline{N}^{4}+3,8372\overline{N}^{3}-1,2194\overline{N}^{2}+1,0006\overline{N}-0,2337=0.$$

$\overline{N}_1=1,03$ and $\overline{N}_2=0,264$, let us take $\overline{N}=\overline{N}_2=0,264$.

Relative power of buses with diesel engines:

$$\overline{N}=\frac{\left[0,45\cdot 1,293\cdot 7,5\cdot 6,84^{2}+10500\cdot 9,87\cdot \cos 4\cdot \left(0,02-tg4\right)-6,698\cdot 10500\right]\cdot 6,84}{150000\cdot \left(-1,3238\overline{N}^{3}+1,118\overline{N}^{2}-0,031\overline{N}+0,8755\right)}.$$

It follows:

$$-1,3238\overline{N}^{4}+1,118\overline{N}^{3}-0,031\overline{N}^{2}+0,8755\overline{N}-0,317=0.$$

$\overline{N}_1=1,15$ and $\overline{N}_2=0,347$, let us take $\overline{N}=\overline{N}_2=0,347$.

Let us calculate the relative coefficient of excess air (table 1) using the method [9, 10].

Table 1

Relative coefficient of excess air of motor vehicles

Motor vehicle	Engine type and type of fuel used	$\bar{N}$	$\bar{\alpha}$
Passenger vehicles	carburetor-type petrol engines	0.516	$\bar{\alpha}=0,8775\cdot 0,516^3-2,1263\cdot 0,516^2+2,0224\cdot 0,516+$ $+0,2387=0,837$
	injection-type petrol engines	0.53	$\bar{\alpha}=1,4577\cdot 0,53^3-3,3985\cdot 0,53^2+2,8352\cdot 0,53+$ $+0,1276=0,893$
	diesel engines	0.445	–
	gas engines	0.562	$\bar{\alpha}=0,8775\cdot 0,562^3-2,1263\cdot 0,562^2+2,0224\cdot 0,562+$ $+0,2387=0,859$
Minibuses	carburetor-type petrol engines	0.254	$\bar{\alpha}=0,8775\cdot 0,254^3-2,1263\cdot 0,254^2+2,0224\cdot 0,254+$ $+0,2387=0,63$
	injection-type petrol engines	0.265	$\bar{\alpha}=1,4577\cdot 0,265^3-3,3985\cdot 0,265^2+2,8352\cdot 0,265+$ $+0,1276=0,667$
	diesel engines	0.263	–
	gas engines	0.346	$\bar{\alpha}=0,8775\cdot 0,346^3-2,1263\cdot 0,346^2+2,0224\cdot 0,346+$ $+0,2387=0,72$
Cargo vehicles	carburetor-type petrol engines	0.274	$\bar{\alpha}=0,8775\cdot 0,274^3-2,1263\cdot 0,274^2+2,0224\cdot 0,274+$ $+0,2387=0,651$
	injection-type petrol engines	0.285	$\bar{\alpha}=1,4577\cdot 0,285^3-3,3985\cdot 0,285^2+2,8352\cdot 0,285+$ $+0,1276=0,693$
	diesel engines	0.395	–
	gas engines	0.606	–
Buses	carburetor-type petrol engines	0.253	$\bar{\alpha}=0,8775\cdot 0,253^3-2,1263\cdot 0,253^2+2,0224\cdot 0,253+$ $+0,2387=0,628$
	injection-type petrol engines	0.264	$\bar{\alpha}=1,4577\cdot 0,264^3-3,3985\cdot 0,264^2+2,8352\cdot 0,264+$ $+0,1276=0,666$
	diesel engines	0.347	–

Depending on the relative power of the motor vehicle, we calculate the NO_x concentration in the exhaust gases (ED) of the motor vehicle using formulas [10].

Passenger vehicles with carburetor-type petrol engines:

$$c=35,536\cdot 0,837^2-73,553\cdot 0,837+39,411=2,743 \text{ g/m}^3.$$

Passenger vehicles with injection-type petrol engines:

$$c=18,667\cdot 0,893^2-41,8\cdot 0,893+24,043=1,602 \text{ g/m}^3.$$

Passenger vehicles with diesel engines:

$$c=4,2667\cdot 0,445^4-19,2\cdot 0,445^3+18,933\cdot 0,445^2-1,2\cdot 0,445+0,7=2,391 \text{ g/m}^3.$$

Passenger vehicles with gas engines:

$$c = 18,667 \cdot 0,859^2 - 41,8 \cdot 0,859 + 24,043 = 1,911 \text{ g/m}^3.$$

Minibuses with carburetor-type petrol engines:

$$c = -58,578 \cdot 0,63^2 + 62,586 \cdot 0,63 - 9,5996 = 6,58 \text{ g/m}^3.$$

Minibuses with injection-type petrol engines:

$$c = -50,5 \cdot 0,667^2 + 51,98 \cdot 0,667 - 7,1382 = 5,066 \text{ g/m}^3.$$

Minibuses with diesel engines:

$$c = 4,2667 \cdot 0,263^4 - 19,2 \cdot 0,263^3 + 18,933 \cdot 0,263^2 - 1,2 \cdot 0,263 + 0,7 = 1,365 \text{ g/m}^3.$$

Minibuses with gas engines:

$$c = -50,5 \cdot 0,72^2 + 51,98 \cdot 0,72 - 7,1382 = 4,108 \text{ g/m}^3.$$

Cargo vehicles with carburetor-type petrol engines:

$$c = -58,578 \cdot 0,651^2 + 62,586 \cdot 0,651 - 9,5996 = 6,318 \text{ g/m}^3.$$

Cargo vehicles with injection-type petrol engines:

$$c = -50,5 \cdot 0,693^2 + 51,98 \cdot 0,693 - 7,1382 = 4,631 \text{ g/m}^3.$$

Cargo vehicles with diesel engines:

$$c = 4,2667 \cdot 0,395^4 - 19,2 \cdot 0,395^3 + 18,933 \cdot 0,395^2 - 1,2 \cdot 0,395 + 0,7 = 2,101 \text{ g/m}^3.$$

Cargo vehicles with gas engines:

$$c = 0,3987 \cdot 0,606^2 - 0,0327 \cdot 0,606 + 0,0474 = 0,174 \text{ g/m}^3.$$

Buses with carburetor-type petrol engines:

$$c = -58,578 \cdot 0,628^2 + 62,586 \cdot 0,628 - 9,5996 = 6,602 \text{ g/m}^3.$$

Buses with injection-type petrol engines:

$$c = -50,5 \cdot 0,666^2 + 51,98 \cdot 0,666 - 7,1382 = 5,081 \text{ g/m}^3.$$

Buses with diesel engines:

$$c = 4,2667 \cdot 0,347^4 - 19,2 \cdot 0,347^3 + 18,933 \cdot 0,347^2 - 1,2 \cdot 0,347 + 0,7 = 1,823 \text{ g/m}^3.$$

Let us calculate the volume flow of exhaust gases using the formula:

$$Q_{OГj} = 0,0007v^2 - 0,256v + 0,3184 .$$

Volume flow of exhaust gases of passenger cars:

$$Q_{OГj1} = 0,0007 \cdot 15,31^2 - 0,0256 \cdot 15,31 + 0,3184 = 0,091 \text{ m}^3\text{/s}.$$

Volume flow of exhaust gases of minibuses:

$$Q_{OГj2} = 0,0007 \cdot 8,8^2 - 0,0256 \cdot 8,8 + 0,3184 = 0,147 \text{ m}^3\text{/s}.$$

Volume flow of exhaust gases of cargo vehicles and buses:

$$Q_{OГj3,4} = 0,0007 \cdot 6,84^2 - 0,0256 \cdot 6,84 + 0,3184 = 0,176 \text{ m}^3\text{/s}.$$

Let us calculate the mass flow of NO_x for cars by purpose and type of fuel using the formula:

$$M_{jk} = c \cdot Q_{OГj} .$$

Table 2 provides the calculation results.

Table 2

Mass flow of NO_x of engines of vehicles [11]

Engines by type of fuel used	Engines by type of fuel used Mass emission of pollutants by vehicles by purpose M_{jk}, g/s			
	Passenger cars	Minibuses	Cargo vehicles	Buses
carburetor-type petrol engines	0.2488	0.9673	1.112	1.162
injection-type petrol engines	0.1458	0.7447	0.8151	0.8943
diesel engines	0.2176	0.2007	0.3698	0.3208
gas engines	0.1739	0.6039	0.0306	-

The average spatial interval between cars on a section of the road network is calculated using the formula:

$$h(v_{m.n.}) = 0,285_{m.n.}^{2} + 0,504 v_{m.n.} + 5,7 .$$

As a result of substituting parameter values, we get:

$$h(v_{m.n.}) = 0,285 \cdot 8,2^{2} + 0,5048,2 + 5,7 = 11,75 \text{ m.}$$

The volume of traffic on a section of the road network is found by the formula:

$$K = z \cdot \left[\frac{L - d_{cp}}{h(v_{m.n.})} + 1 \right],$$

where d_{cp} — the average length of the vehicle, m. The parameter d_{cp} is taken from the condition that the length of the passenger car is 3 m, minibus — 5 m, cargo vehicle — 6 m and bus — 8.0 m.

As a result of substituting the parameter values, we get:

$$K = \left[\frac{111,6 - 5,5}{11,75} + 1 \right] \cdot 3 = 30,1 \text{ pcs.}$$

Let us calculate the mass flow of NO_x for vehicle types by purpose and type of fuel used using the formula:

$$\sum M_{jk} = M_{jk} K \lambda_{jk} ,$$

where λ_{jk} — the share of vehicles by purpose and type of fuel in the traffic flow.

Table 3 provides the calculation results 3.

Table 3

Mass flow of NO_x for vehicle types

Vehicle	Engine type and type of fuel used	Mass flow of NO_x for vehicles types ΣM_{jk}, g/s
Passenger cars	carburetor-type petrol engines	2.705
	injection-type petrol engines	1.580
	diesel engines	0.0917
	gas engines	0.250
Minibuses	carburetor-type petrol engines	0.670
	injection-type petrol engines	0.524
	diesel engines	0.375
	gas engines	0.727
Cargo vehicles	carburetor-type petrol engines	0.1088
	injection-type petrol engines	0.0798
	diesel engines	0.050
	gas engines	0.00046
Buses	carburetor-type petrol engines	0.736
	injection-type petrol engines	0.597
	diesel engines	0.156

Let's determine the mass flow rate of NO_x by the transport flow in a given section by adding the mass flow rate values for all vehicle types from table 3:

$$\sum M = \sum \sum M_{jk} .$$

As a result, we get:

$$\sum M = 2,705 + 1,58 + 0,0917 + 0,25 + 0,67 + 0,514 + 0,375 + 0,727 + 0,1088 + 0,0798 +$$

$$+0,05+0,00046+0,736+0,597+0,156=8,64 \text{ g/s.}$$

Thus, the speed of the transport flow will increase by 17.1%, and the mass flow of NO_x in a given section will decrease by 23.2% (from 11.2 to 8.64 g/s).

Conclusion. Based on the results of the calculation, it can be concluded that these measures are necessary to significantly reduce the negative consequences that road transport creates on a given section of the road network. The less traffic congestion, the higher the capacity of the section. Cars will not wait, and that will reduce emissions into the atmosphere, increase environmental safety, and improve the organization of traffic at the selected intersection.

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